Learning To Edit Code

Ph.D. Defense Presentation

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Automatic Code Editing

Adding Feature

```
public String removeComment(String leftOver) {
-   if (hasBlockComment(leftOver)){
+   while (hasBlockComment(leftOver)){
        leftOver = removeBlockComment(leftOver);
    }
-   if (hasLineComment(leftOver)){
+   while (hasLineComment(leftOver)){
        leftOver = removeLineComment(leftOver);
    }
    return leftOver;
}
```

Adding Feature

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public String removeComment(String leftOver) {
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Bug-fixing

```
public abstract void removeSessionCookies()
                                throws Exception { ;
-     throw new MustOverrideException();
- }
```

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Bug-fixing

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public abstract void removeSessionCookies()
                                    throws Exception { ;
-     throw new MustOverrideException();
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Refactoring

```
void visit(JSession *session, Timer t) throws Exception {
    if (*session != null && t.getTime() > *session.getStartTime()){
        visit((JNode) *session, t);
    }
    else {
        visit(new JNode(), new Timer());
    }
}
```

Code Edits Are Repetitive

```
    ...
-   if (this.equals(object)){
+   if (this == object){
        ...
    }
    ...
```

```
    ...
-   return super.equals(object);
+   return this == object;
```

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    ...
-   if (super.equals(object)){
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Code Edits Are Repetitive (Meng *et. al.* 2011[1], 2013[2], Ray *et. al.* 2015[3])

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Is it possible to
Automate
Such Code Edits?

Automating Code Edits - Template/Search based

```
        Edit Template
    ...
-   return super.equals(object);
+   return this == object;
    ...
```

Automating Code Edits - Template/Search based

Edit Template

```
     ...
-    return super.equals(object);
+    return this == object;
     ...
```

```
public Model copy(Model instance){
    ...
    instance.notify();
    if (super.equals(instance) && !instance.isEmpty()){
        return instance.clone();
    }
    ...
}
```

Automating Code Edits - Template/Search based

Edit Template

```
      ...
-     return super.equals(object);
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```

Match Found

```
public Model copy(Model instance){
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Automating Code Edits - Template/Search based

Edit Template

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Patch Applied

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```

- **Too many templates** to write (Saha et al.[22])

Code Editing Task - Learning Based Solution

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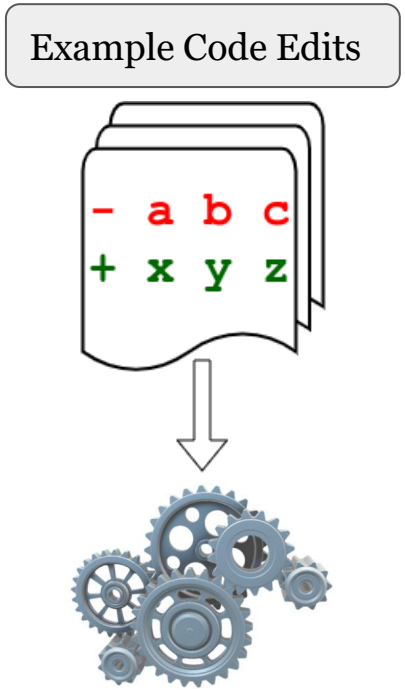
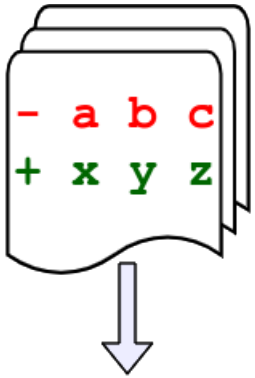


Code Editing Task - Learning Based Solution

Example Code Edits

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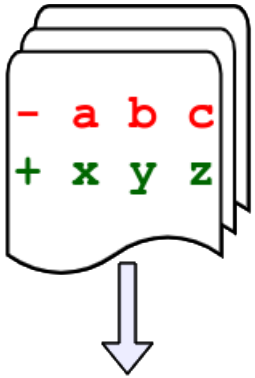
Code Before Edit

Code Editing Task - Learning Based Solution

Example Code Edits

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Code Before Edit

```
return this == object
```

Code After Edit

What are my Contributions?

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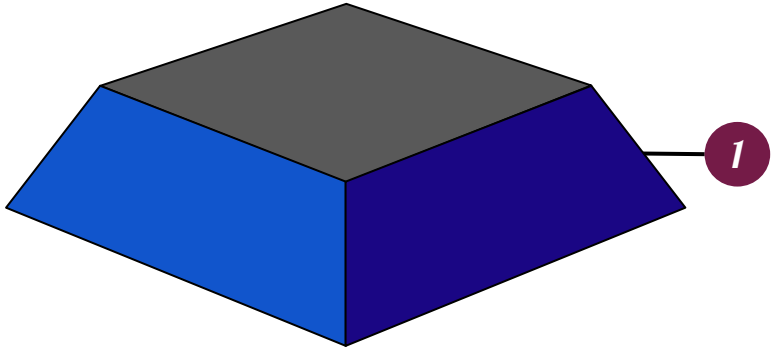
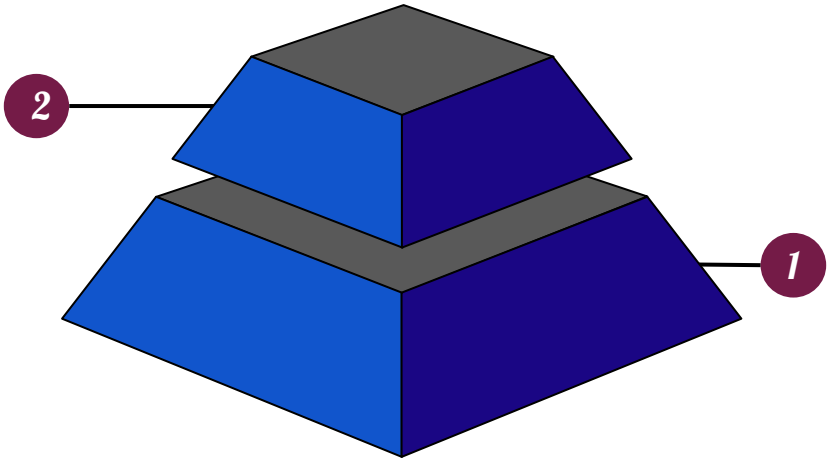


Identification of Technical Challenges in Learning based Code Editing.

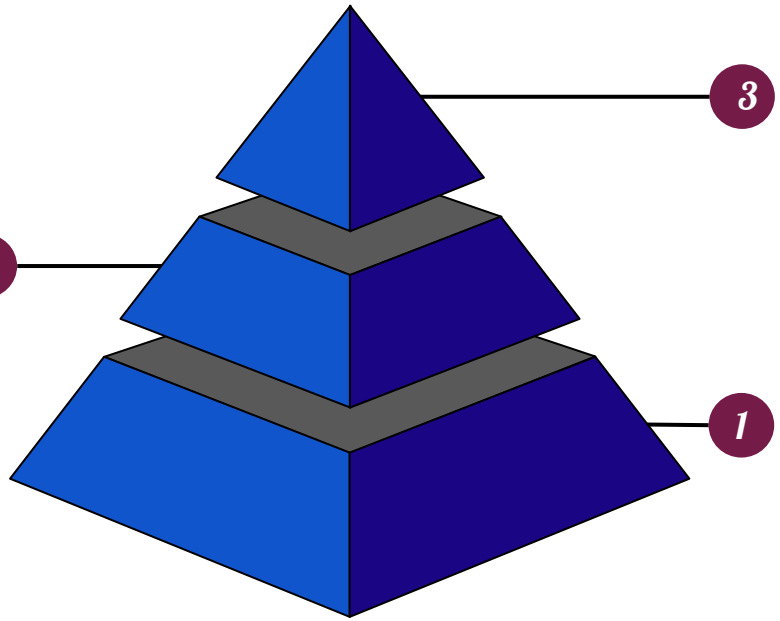
What are my Contributions?

Development of Models for Automated Code Editing.



Identification of Technical Challenges in Learning based Code Editing.

What are my Contributions?



3 **Application** in **Automatic Program Repair** and **Other SE tasks.**

2 **Development of Models** for Automated Code Editing.

1 **Identification of Technical Challenges** in Learning based Code Editing.

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Automated Code Editing - Existing works.

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Template-based

1. Modern IDE (Eclipse, IntelliJ IDEA) - Refactoring, Boilerplate Code.
2. Meng et.al. - PLDI'11 - Infer edit template with graph matching [1].

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Mutation Learning

1. Rolim et. al. - ICSE'17 - Designed a DSL for representing Edits [4].
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Encoder-Decoder

1. Tufano et. al. - ASE'18 [6], ICSE'19 [7], TOSEM'19 [8].
   - Abstract tokenization.
2. Chen et. al. - TSE'19 - Copy Attention-based models [9].
3. Tufano et. al. - ICSE'21. - Multi-Encoder models[10].

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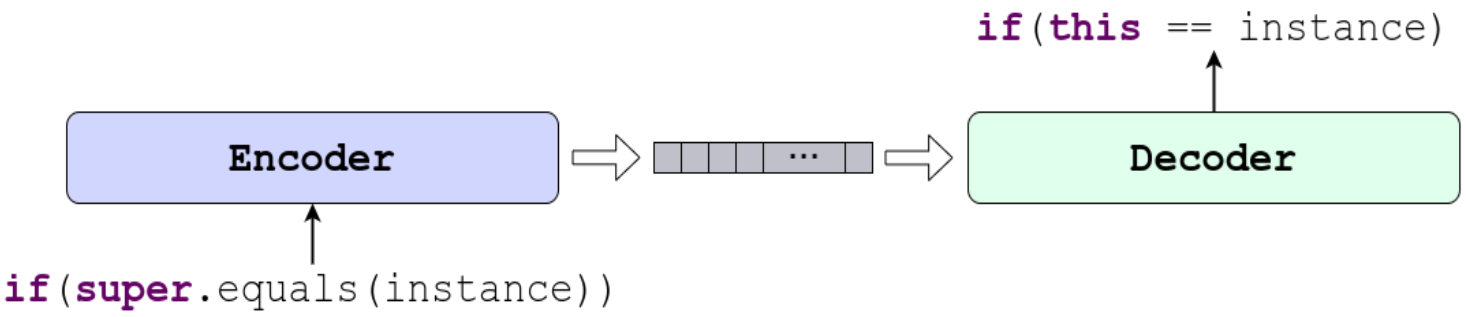
Encoder-Decoder Based Code Editing

Code Editing with Encoder-Decoder



Encoder and **Decoder** learns **Edit Pattern** and
To **Apply the Pattern** in **Similar Context**.

Encoder-Decoder Based Code Editing

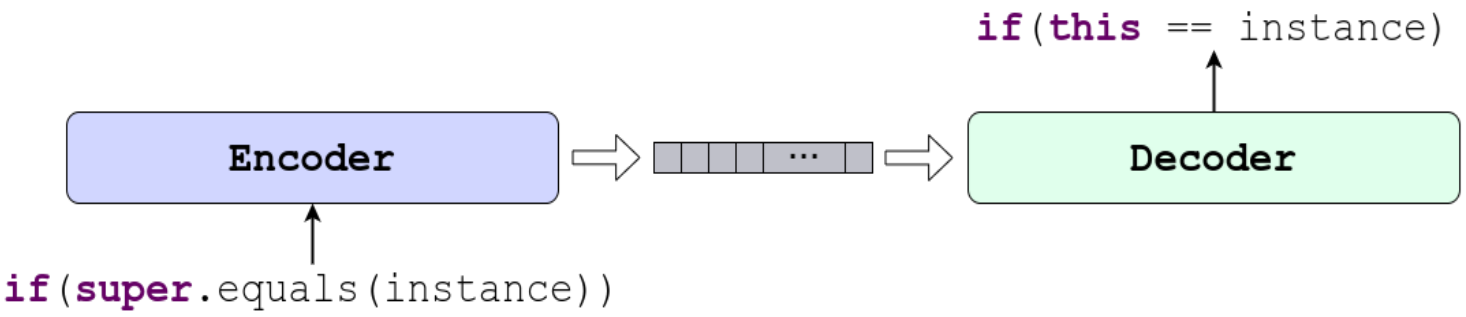
Where does my dissertation stand?

Method	Concrete Code	Syntactic Correctness	Contextual Correctness	Code Naturalness	Multi Modality
M. Tufano *et. al.* ASE 2018 [6], ICSE 2019 [7]	✗	⚠	⚠	✗	✗
SequenceR - Chen *et. al.* TSE 2019 [9]	✓	⚠	⚠	⚠	✗
CODIT - TSE 2020	✓	✓	⚠	⚠	✗
CodeBERT* - Feng *et. al.* EMNLP 2020 [11]	✓	Empirical	Empirical	⚠	✗
PLBART - NAACL 2021	✓	Empirical	Empirical	⚠	✗
CoCoNut - Lutellier *et. al.* ISSTA 2020 [12]	✓	⚠	⚠	⚠	✓
R. Tufano *et. al.* - ICSE 2021 [10]	✗	⚠	⚠	✗	✓
MODIT – ASE 2021	✓	Empirical	Empirical	⚠	✓
NatGen – FSE 2022	✓	Empirical	Empirical	Empirical	✓

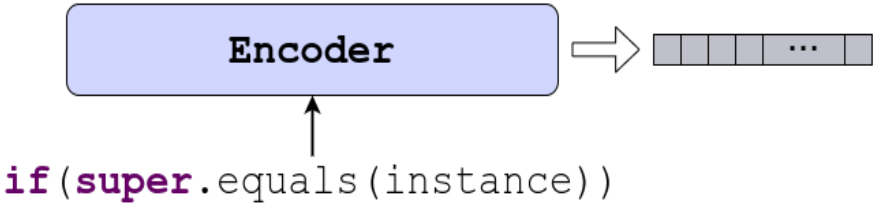
✓ Used/Guaranteed ✗ Not Used ⚠ No guarantee Empirical guarantee

* While CodeBERT is an encoder only pretrained model, it has been used for program repair with a transformer decoder trained from scratch.

Code Editing with Encoder-Decoder

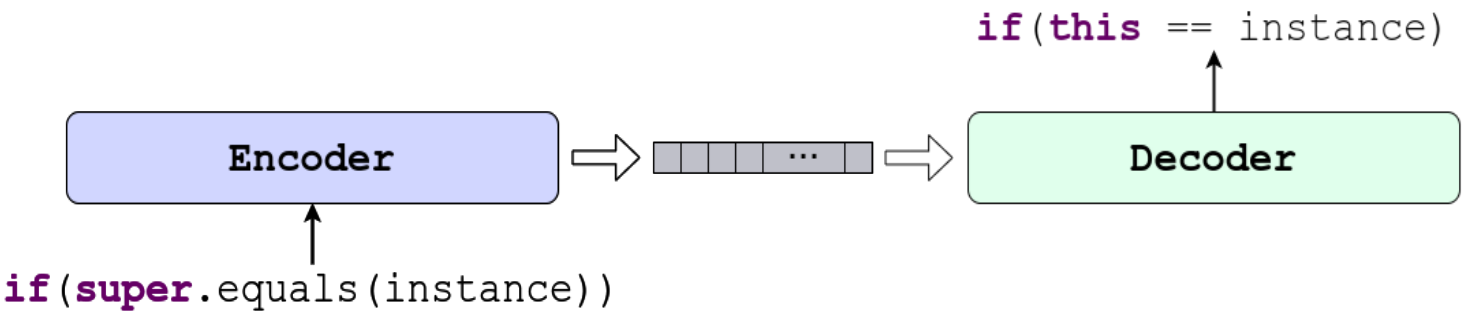


Code Editing with Encoder-Decoder



Encoder encodes the input code to a vector or matrix.

Code Editing with Encoder-Decoder



Decoder generates the edited code.

Desired Properties of Encoder and Decoder

Properties of Source Code.

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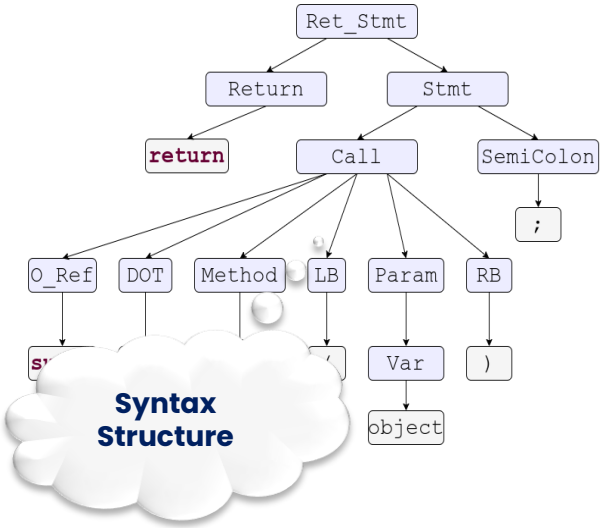
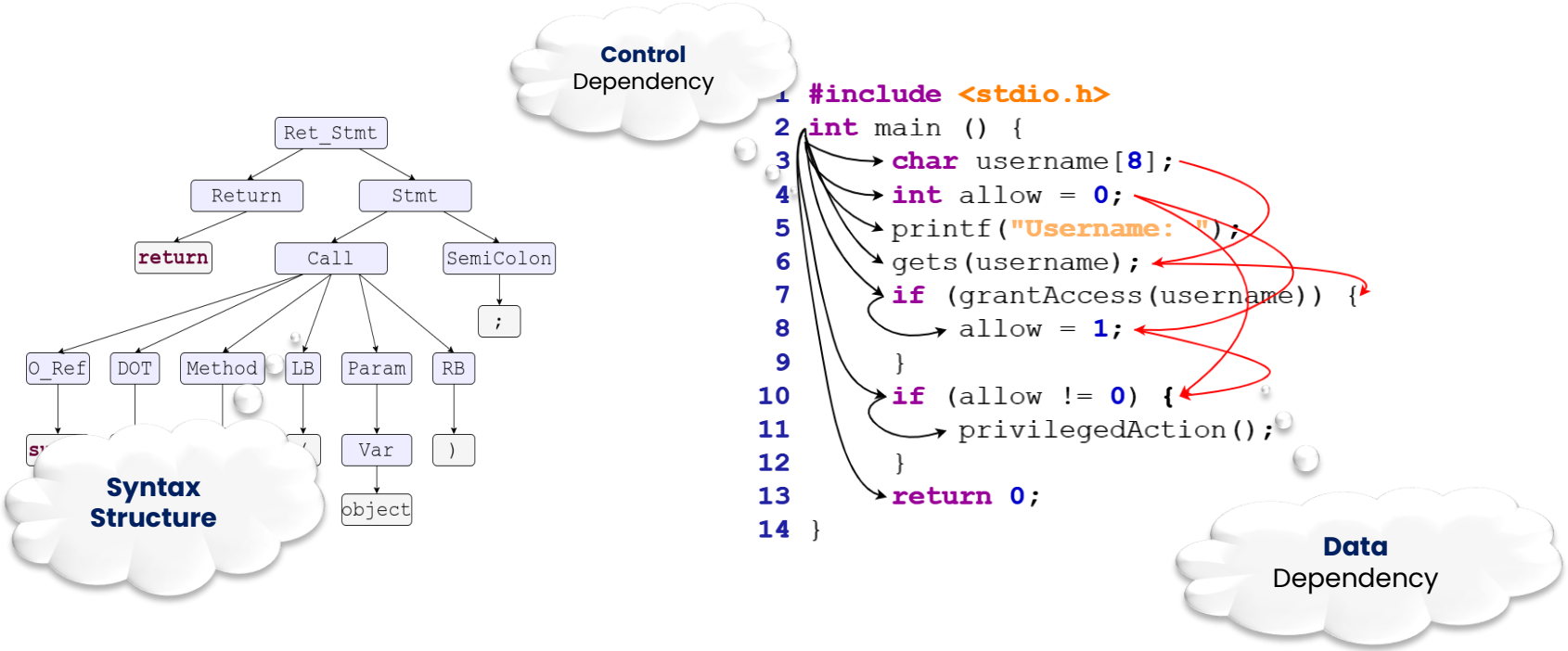
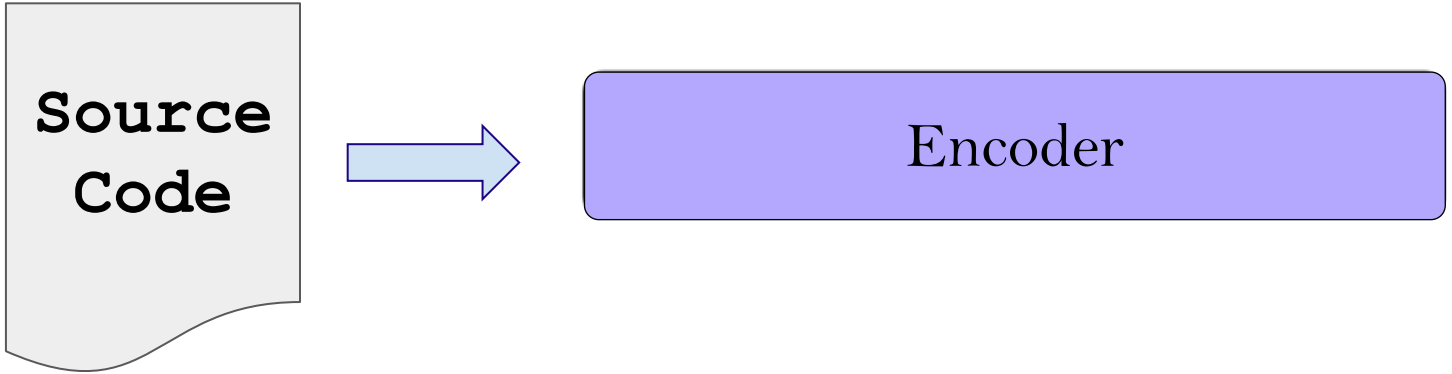


Properties of Source Code.



Desired Properties of the Encoder



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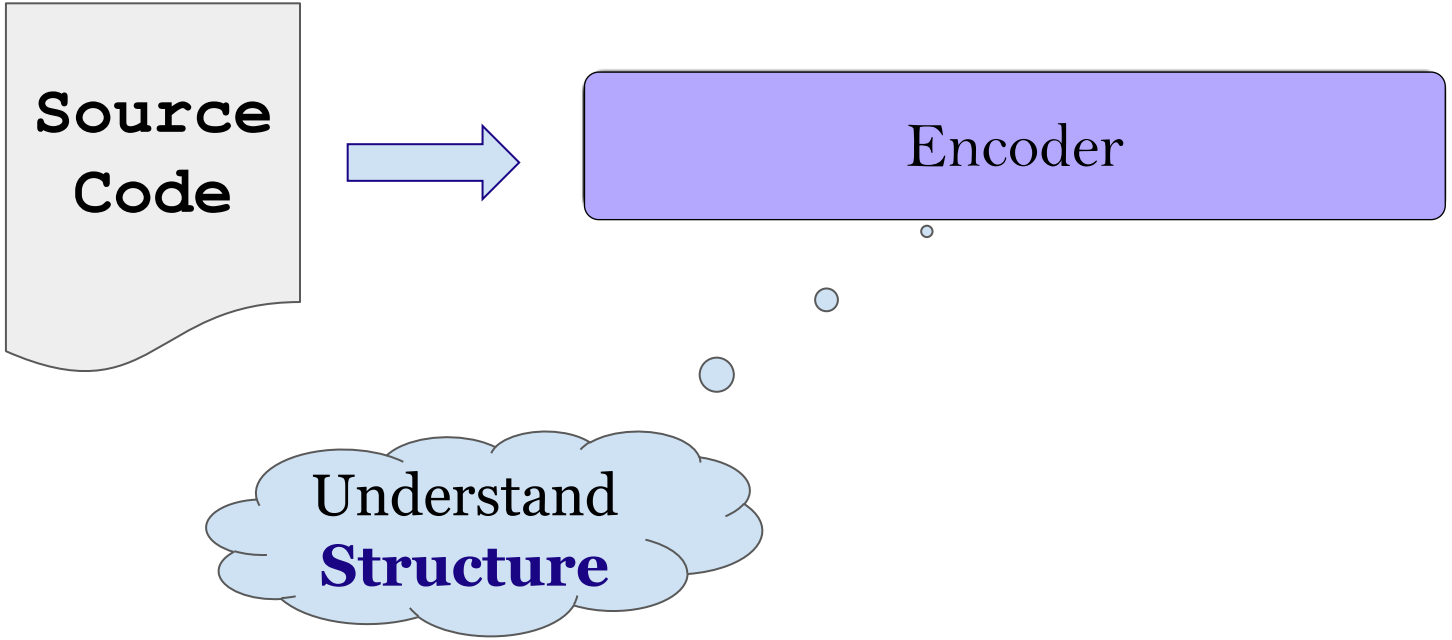

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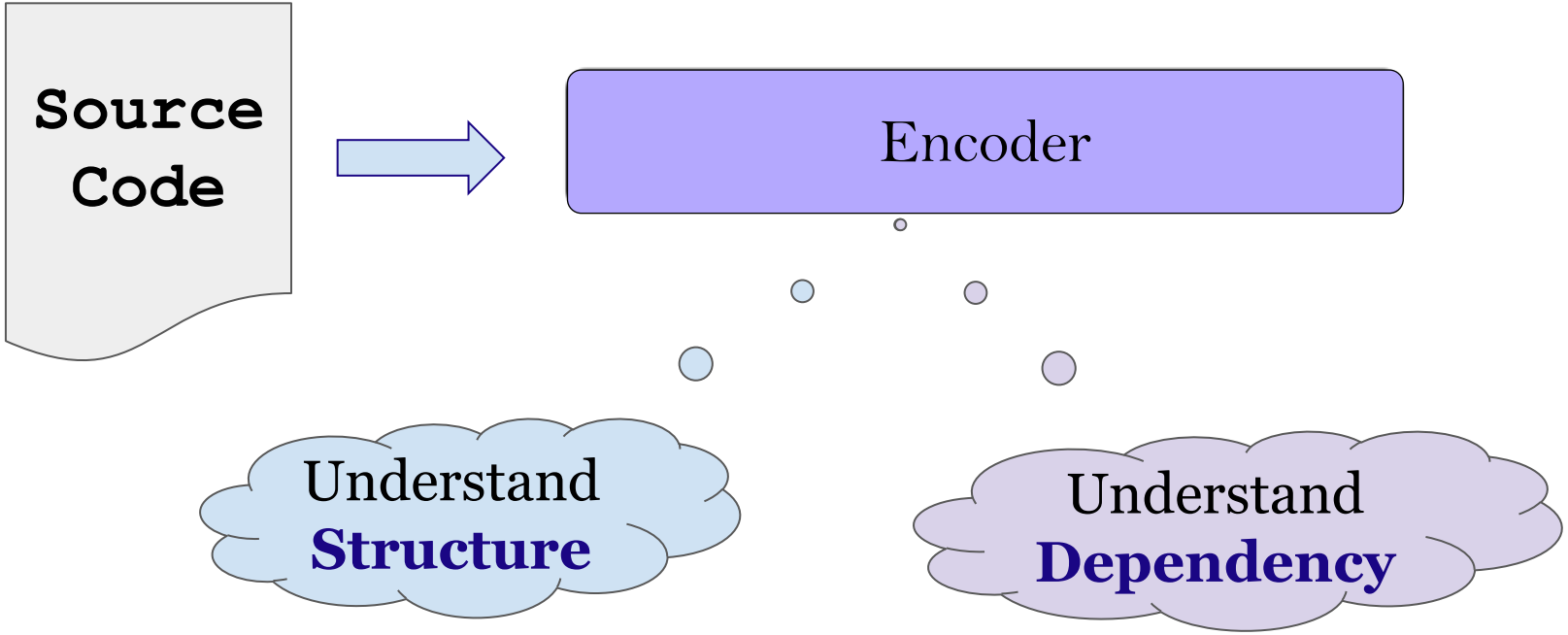

Desired Properties of the Decoder

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return this == object
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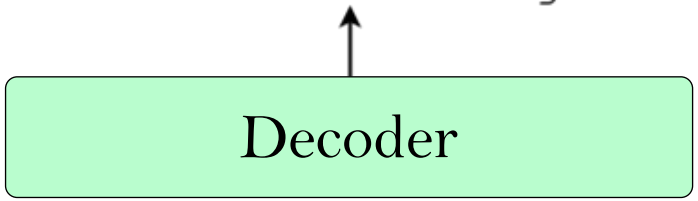

1. Syntactic correctness.
2. Semantic correctness.

Desired Properties of the Decoder

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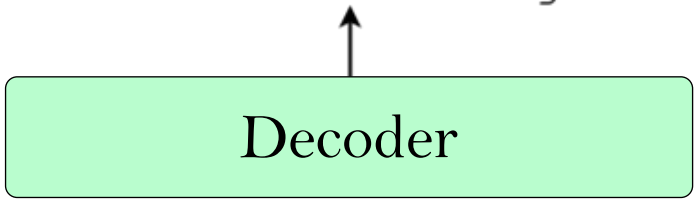

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Syntactically Incorrect

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boolean f (Object target)  {
    for(Object elem : if.elements) {
        if (elem.equals(target)) {
            return true;
        }
    }
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Semantically Incorrect

```
boolean f (Object target)  {
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        if (elem.equals(f)) {
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Desired Properties of the Decoder

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Code Editing as Understanding and Generation

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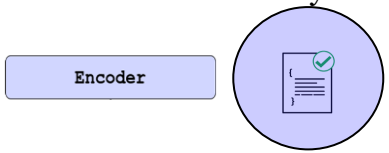
Understanding Source Code

Understanding Structure
And Functionality of Source Code



Code Editing as Understanding and Generation

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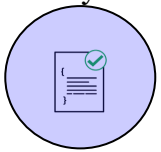
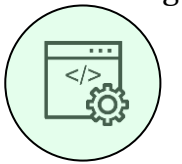
Encoder



Generating Source Code

Ensuring the Syntactic and Semantic
Correctness for Generating Source Code

Decoder



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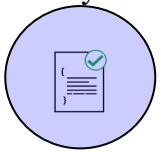

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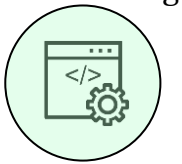
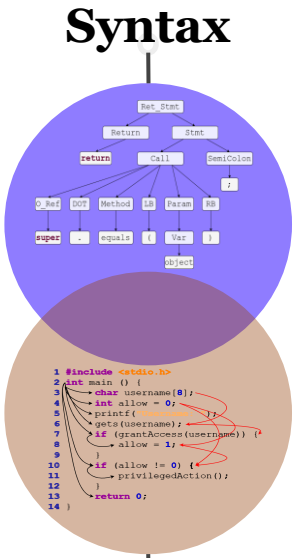
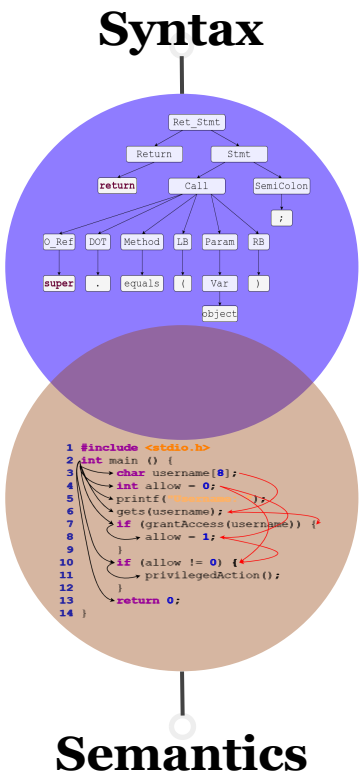


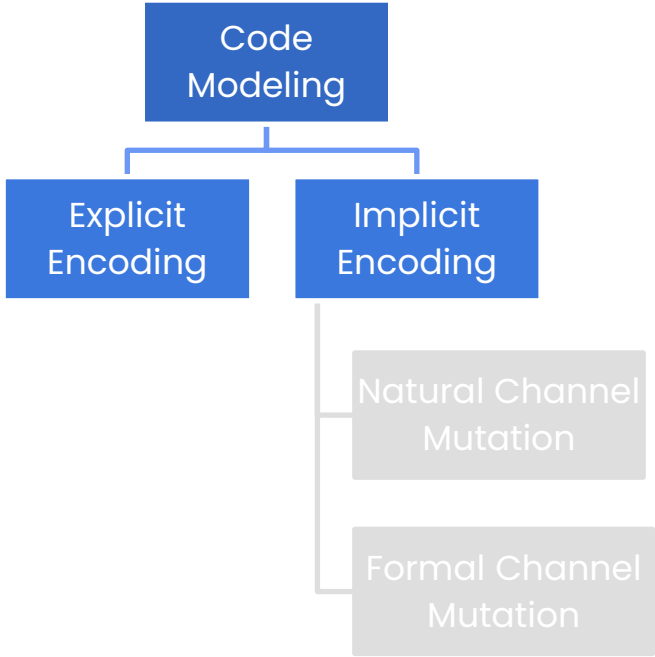


Encoding

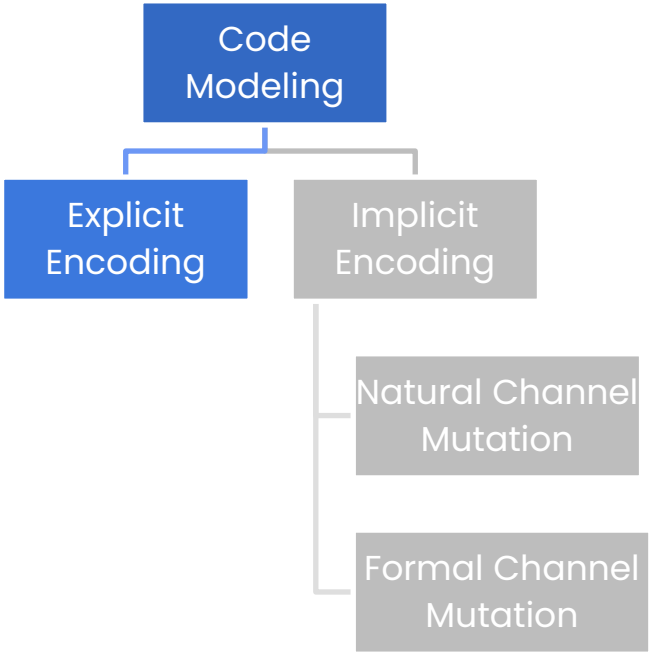
Encoding PL Properties



Ways of Encoding



Explicit Encoding



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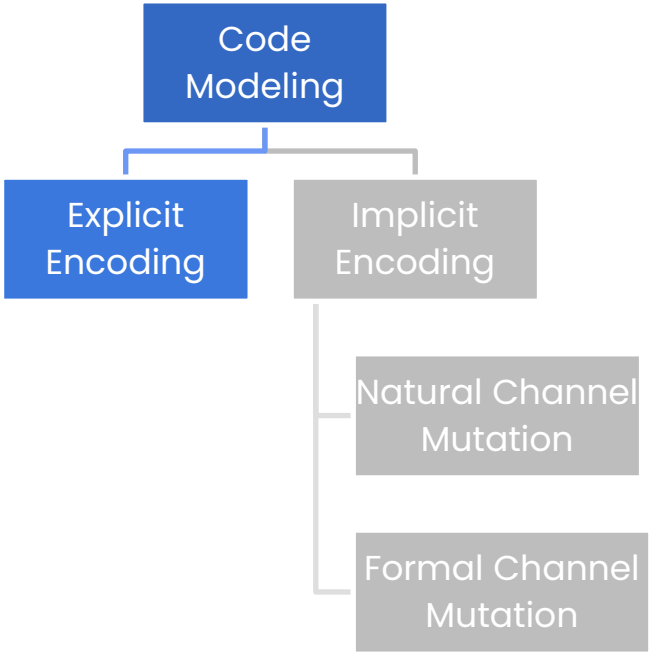

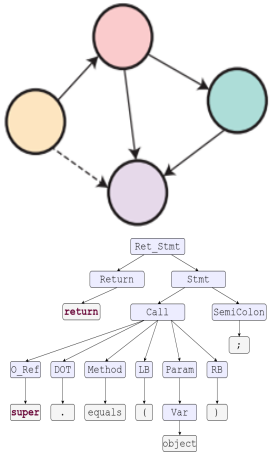

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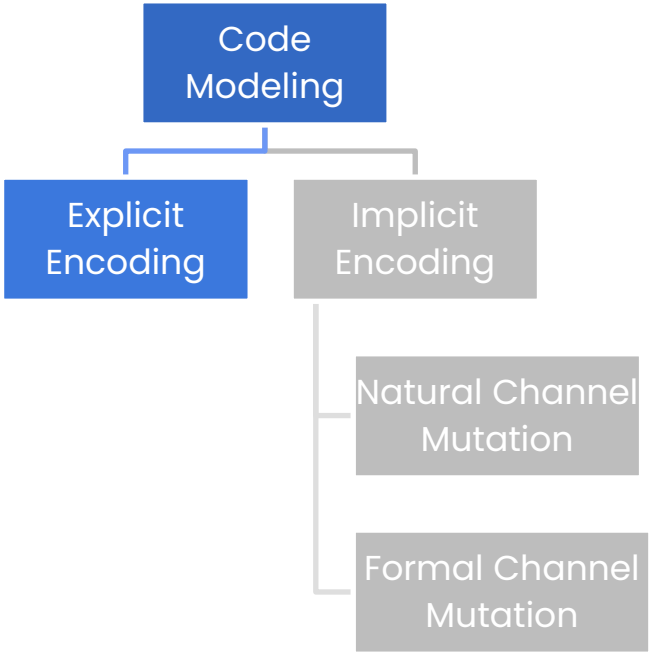

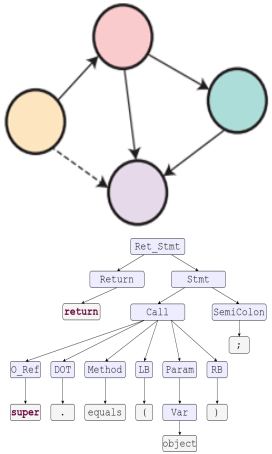

[13] Learning to Represent Program as Graphs
Allamanis et. al. 2017
[14] Learning to Represent Edits
Yin et. al. 2019
[5] HOPPITY – Dinella et. al. 2020

CODIT: Code Editing With Tree Based Neural Models

TSE - 2020

Findings

Generation of Syntax Tree instead of code Guarantees Syntactic Correctness.

Contribution

Tree/Grammar Based Model for Automatic Code Editing.

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CODIT: Code Editing With Tree Based Neural Models

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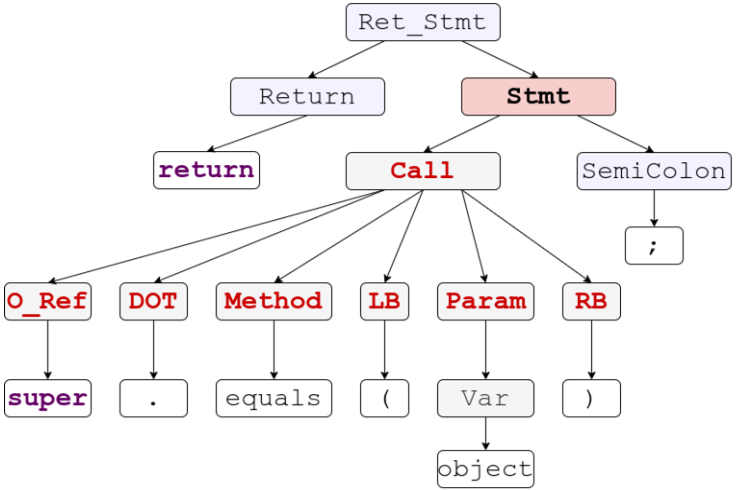

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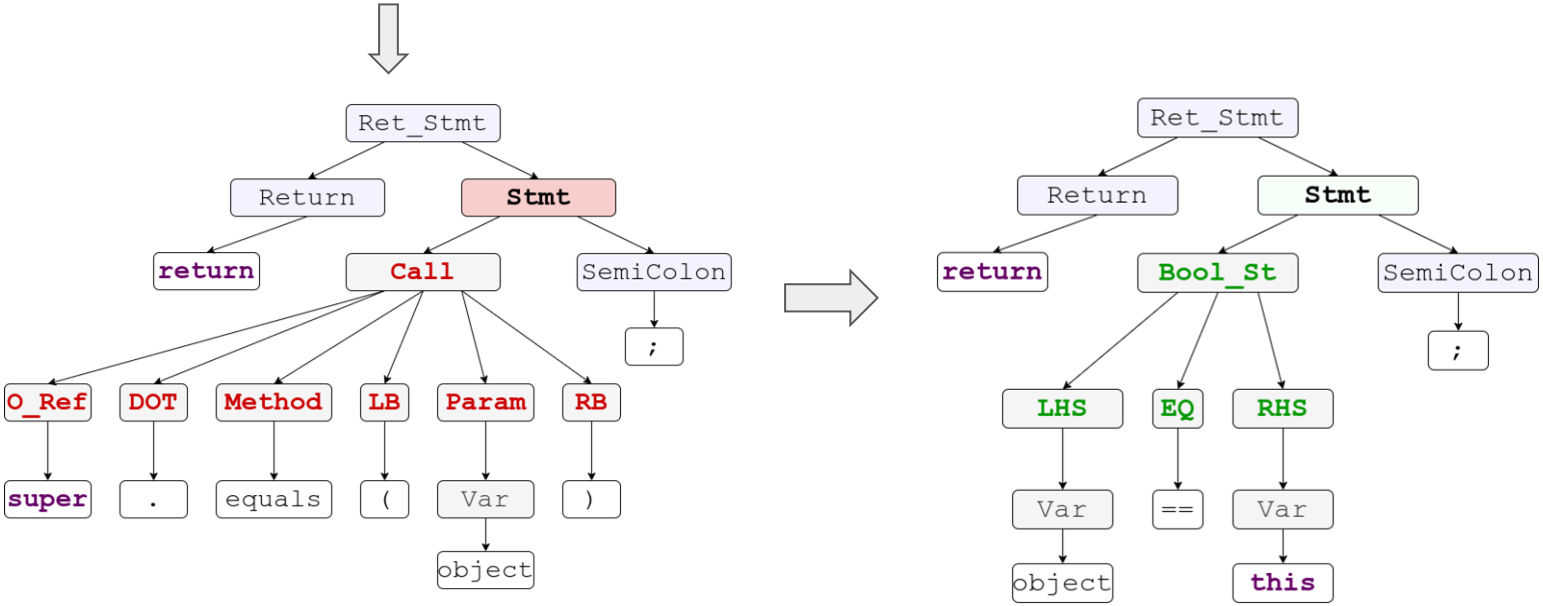
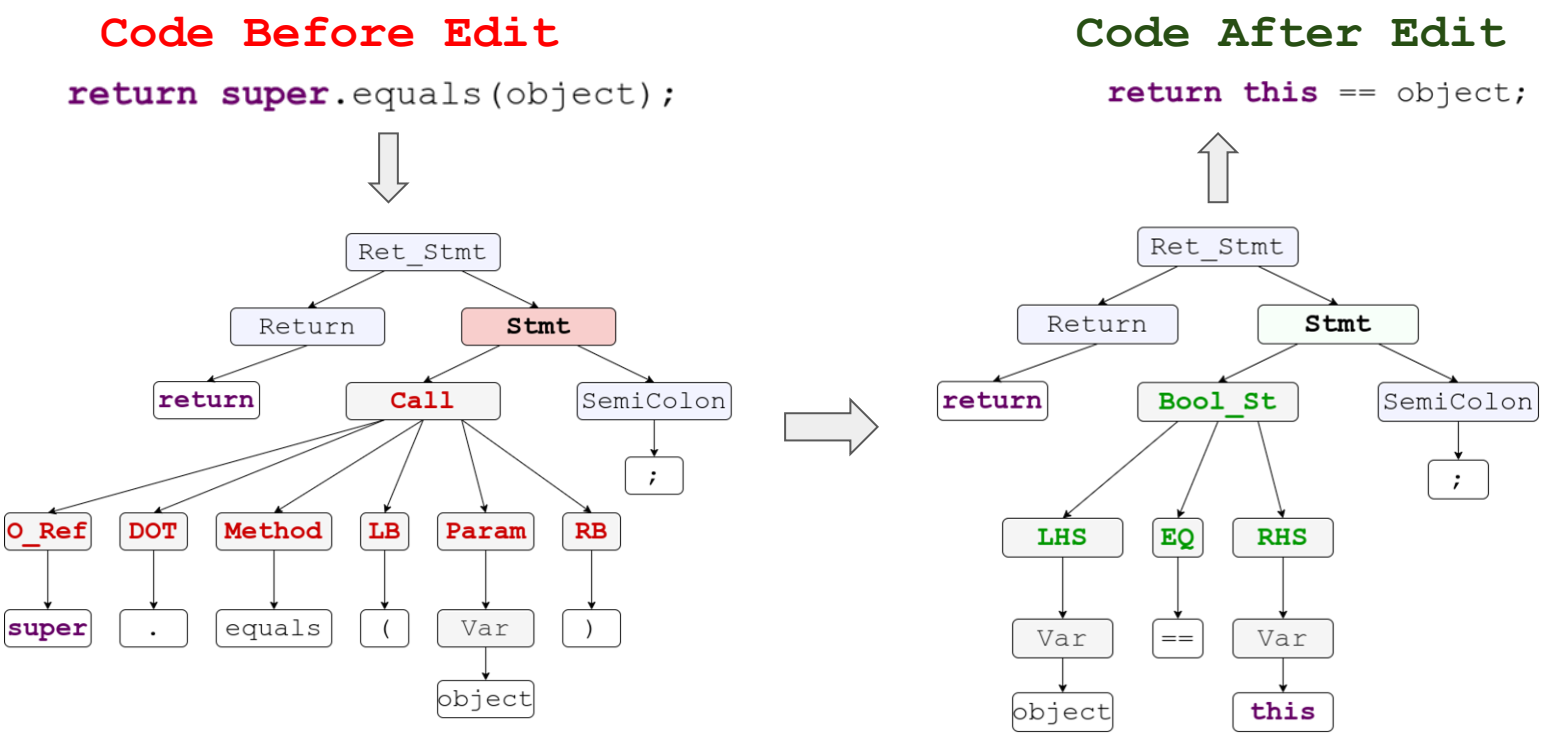


CODIT: Code Editing With Tree Based Neural Models



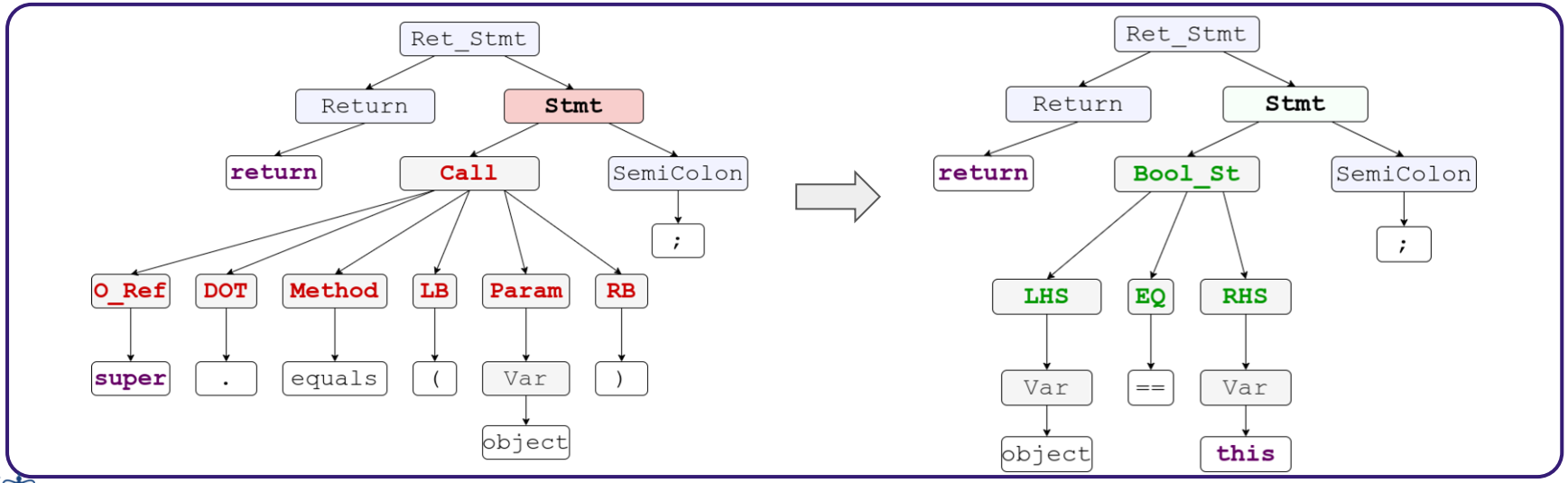
CODIT: Code Editing With Tree Based Neural Models

Code Before Edit

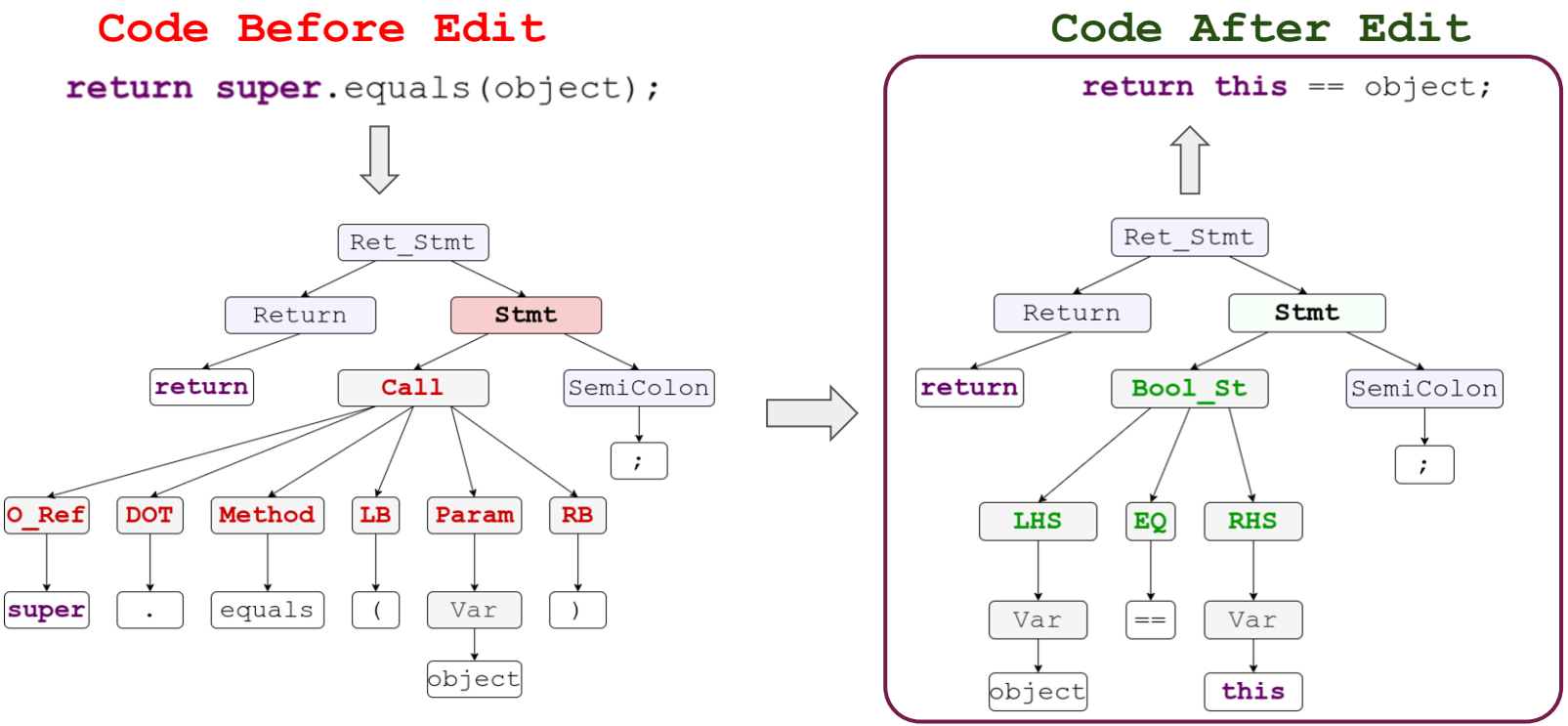
```
return super.equals(object);
```

Code After Edit

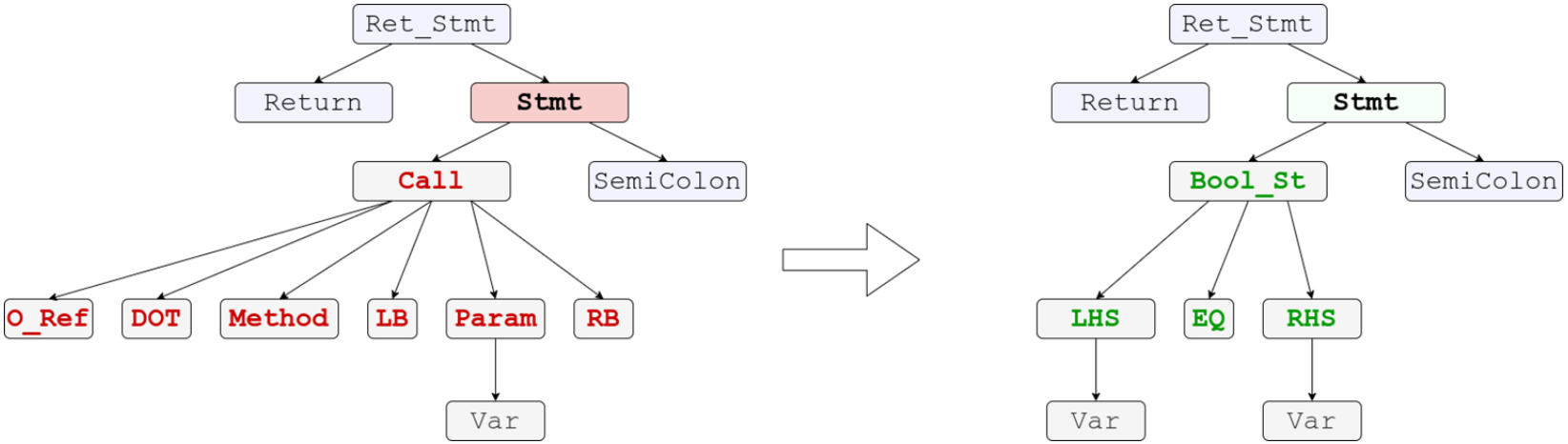
```
return this == object;
```



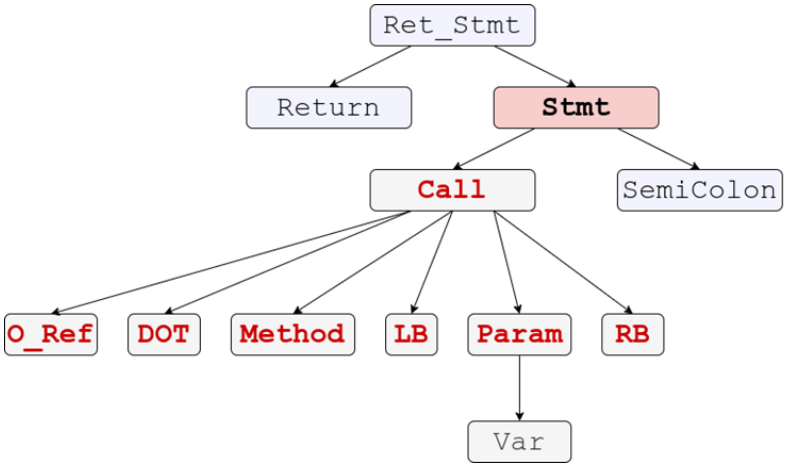
CODIT: Code Editing With Tree Based Neural Models

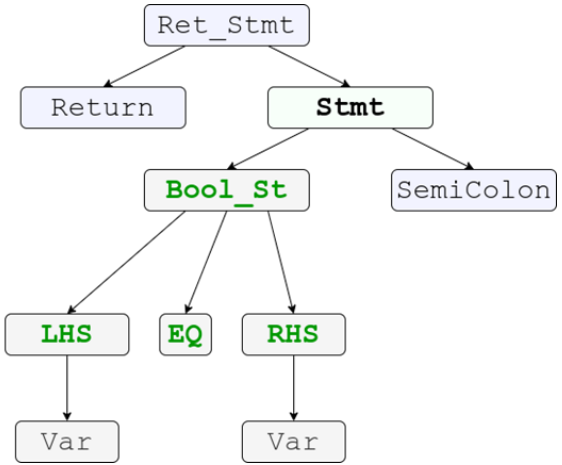


CODIT Step 1 : Tree Translation



CODIT Step 1 : Tree Translation

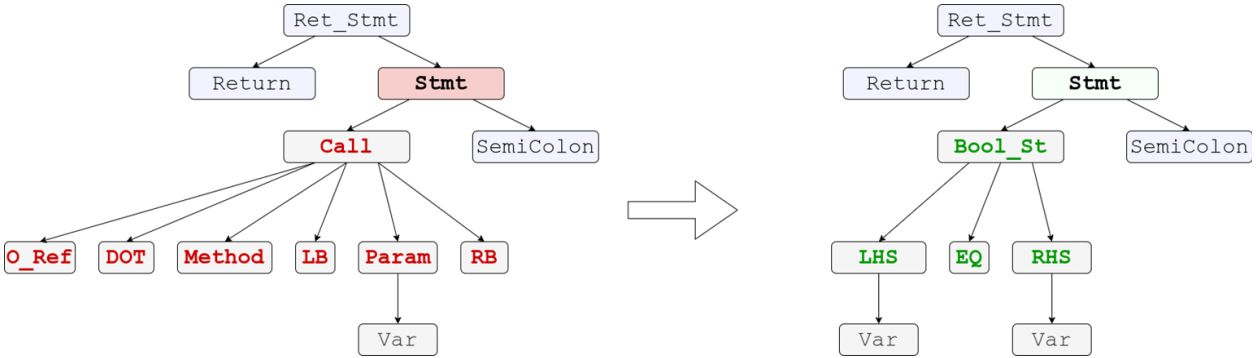




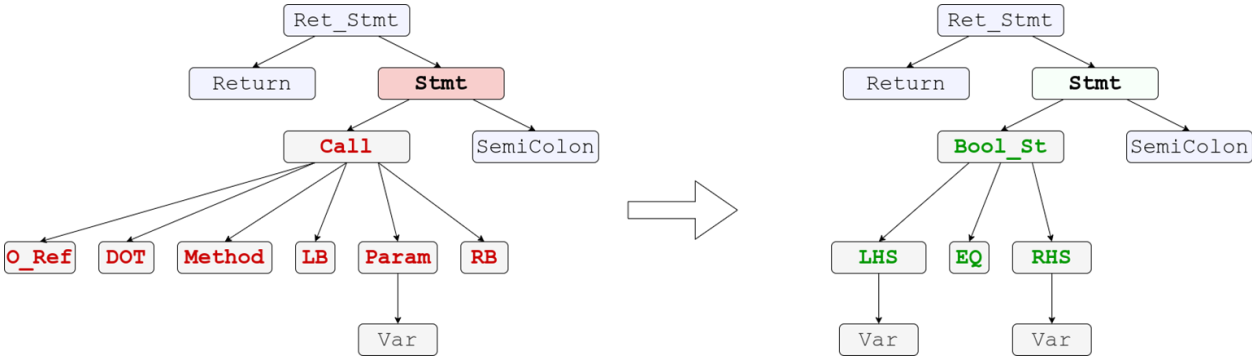

```
Ret_Stmt ──→ Return Stmt
  Stmt   ──→ Call Semicolon
  Call   ──→ O_Ref DOT Method
                LB Param RB
 Param   ──→ Var
```

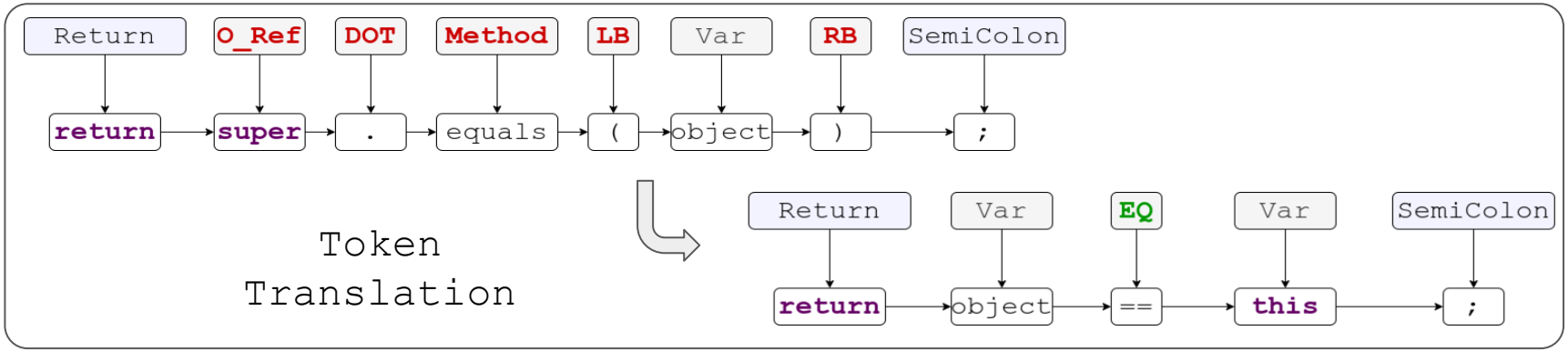
```
Ret_Stmt ──→ Return Stmt
  Stmt   ──→ Bool_St Semicolon
Bool_St  ──→ LHS EQ RHS
  LHS    ──→ VAR
  RHS    ──→ VAR
```

CODIT Step 2 : Token Generation

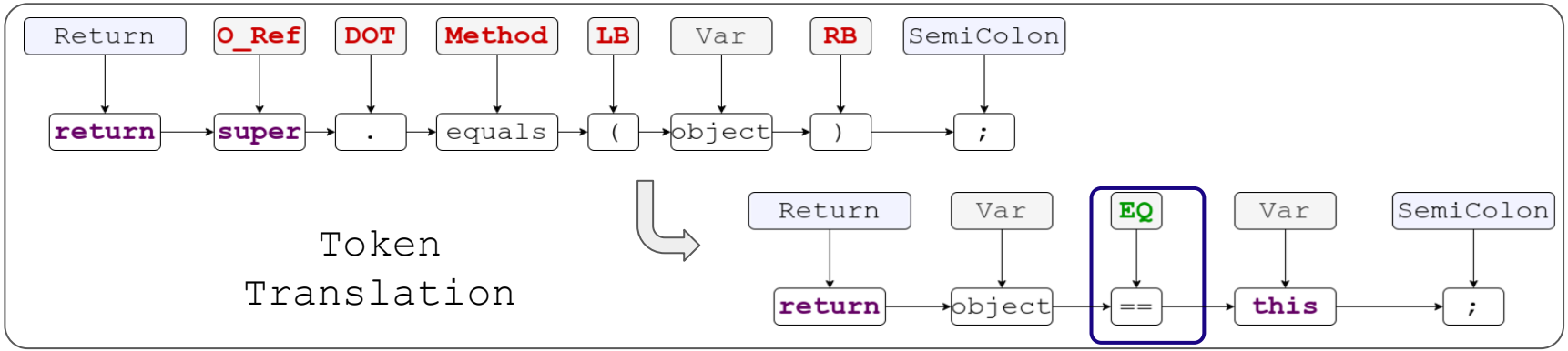


CODIT Step 2 : Token Generation

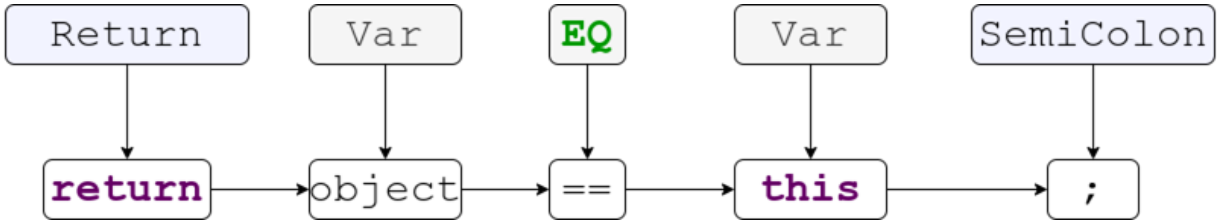




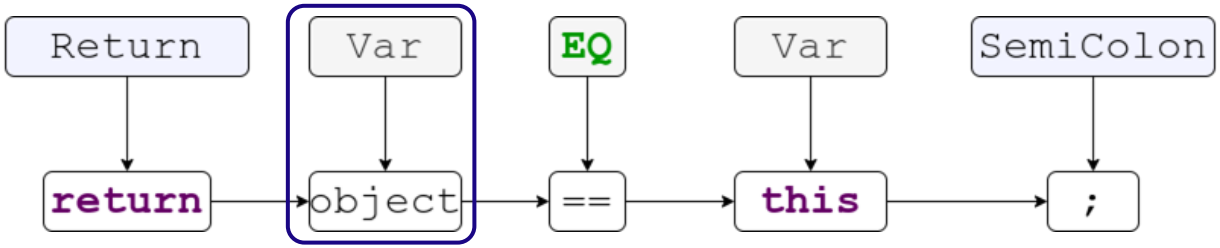
CODIT Step 2 : Token Generation



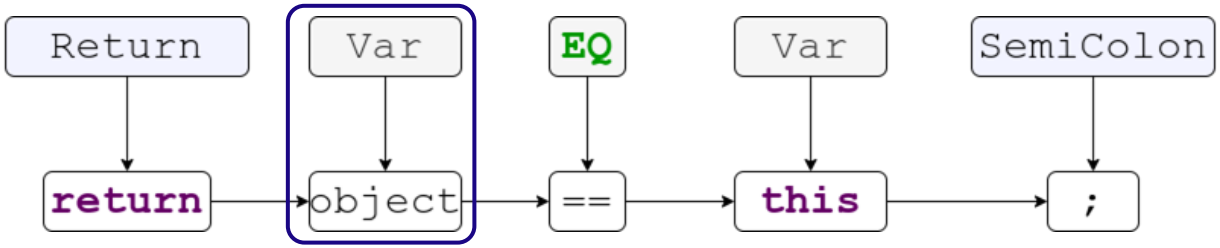
CODIT Step 2 : Token Generation



CODIT Step 2 : Token Generation



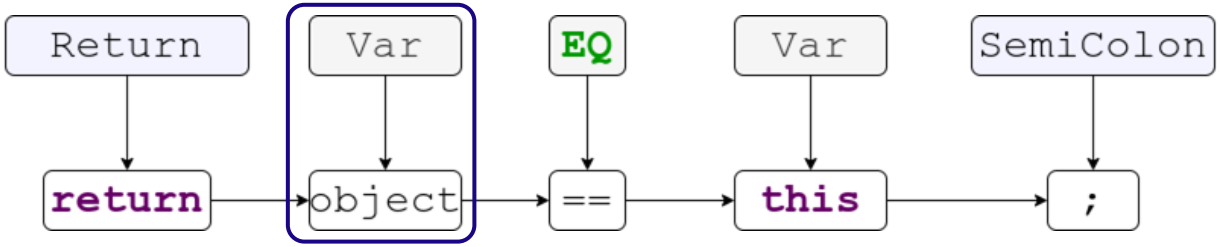
CODIT Step 2 : Token Generation




```
public boolean checkEqual(
            Object inst, MyClass object){
    MyClass tmp = new MyClass();
    if (inst == null) {
        MyClass tmp2 = new MyClass();
        ...
    }
    return super.equals(object);
}
```

Reachability Analysis in Edit Location

CODIT Step 2 : Token Generation




```
public boolean checkEqual(
            Object inst, MyClass object){
    MyClass tmp = new MyClass();
    if (inst == null) {
        MyClass tmp2 = new MyClass();
        ...
    }
    return super.equals(object);
}
```

Reachable Variables in Edit Location:

{inst, object, tmp}

Reachability Analysis in Edit Location

CODIT

Evaluation

CODIT: Study Subjects

Data Set	Number of Projects	Number of Edit Examples	Code Fragment Size	
			Number of Tokens	Number of Nodes
Generic Code Edit from Github	48	32,473	Max - 38 Avg - 15	Max - 47 Avg - 20
Pull Request Edits –Tufano et al. [7]	3	5546	Max - 34 Avg - 17	Max - 47 Avg - 23

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CODIT: Results (Accuracy in top 5)

Method		Generic Code Edits	Pull Request Edit
Sequence Based	LSTM-Seq2Seq	3.77%	11.26%
	Tufano et. al. [7]	6.57%	23.65%
	SequenceR [9]	9.76%	26.43%
Tree Based	Tree2Seq	11.04%	23.49%
	CODIT	**15.94%**	**28.87%**

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Example Edits

```
public void copyFrom( java.lang.Object arr){
+       try{
         android.os.Trace.traceBegin (...);
+       finally{
         android.os.Trace.traceEnd(...);
+       }
}
```

Addition

Deletion

```
public abstract void removeSessionCookies (...)
 {
     throw new android...MustOverrideException();
 }
```

```
void visit(JSession * session , ...) throws Exception
{
    visit (((JNode) (* session)), ...);
}
```

Update

Application - Automatic Program repair

CODIT fixes **15 bugs completely** and **10 bugs partially**, out of 80 bugs in **Defects4j**.

JFreeChart : Bug-8

```
7        public Week(Date time, TimeZone zone) {
8            // defer argument checking...
9  -         this(time, RegularTimePeriod.DEFAULT_TIME_ZONE, Locale.getDefault());
10 +         this(time, zone, Locale.getDefault());
11       }
```

Closure Compiler: Bug-3

```
6        reachingUses = new MaybeReachingVariableUse(cfg, t.getScope(), compiler);
7        reachingUses.analyze();
8        for (Candidate c : candidates) {
9  -       if (c.canInline()) {
10 +       if (c.canInline(t.getScope())) {
11           c.inlineVariable();
```

Explicit Encoding

```
return super.equals(object)
```

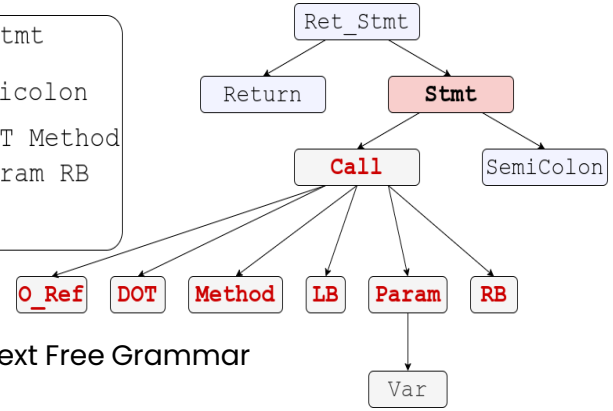
```
return this == object
```

```
Ret_Stmt ⟶ Return Stmt

Stmt     ⟶ Call Semicolon

Call     ⟶ O_Ref DOT Method
            LB Param RB

Param    ⟶ Var
```



Context Free Grammar

Explicit Encoding

```
return super.equals(object)
```

```
return this == object
```

```
public boolean checkEqual(
            Object inst, MyClass object){
    MyClass tmp = new MyClass();
    if (inst == null) {
        MyClass tmp2 = new MyClass();
        ...
    }
    return super.equals(object);
}
```

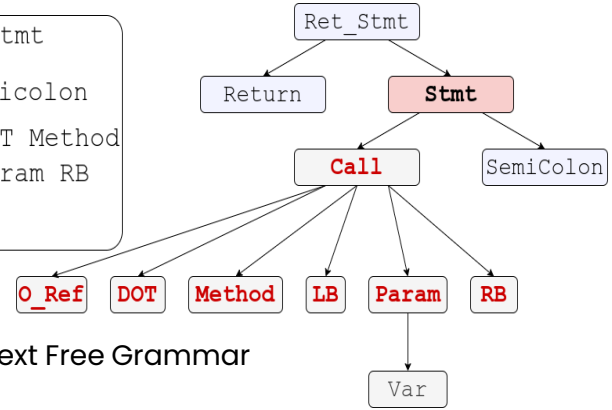
Reachability Analysis

```
Ret_Stmt ——→ Return Stmt

Stmt     ——→ Call Semicolon

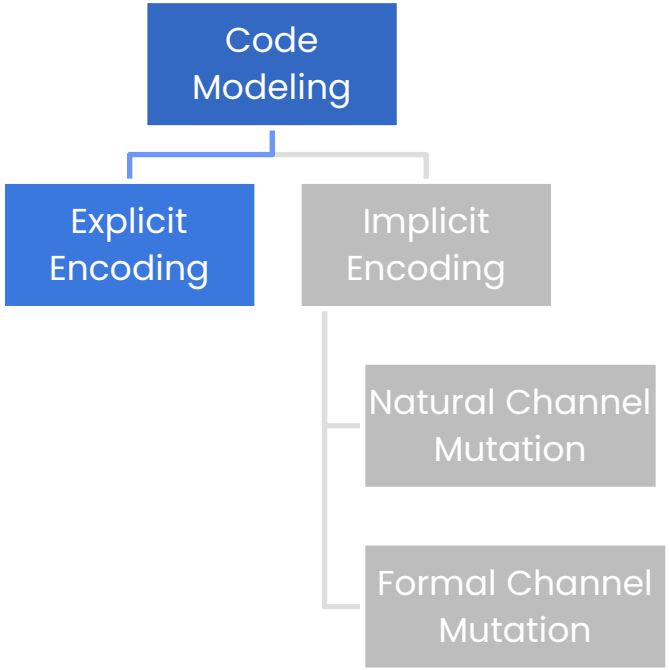
Call     ——→ O_Ref DOT Method
                LB Param RB

Param    ——→ Var
```



Context Free Grammar

Explicit Encoding – Take Away



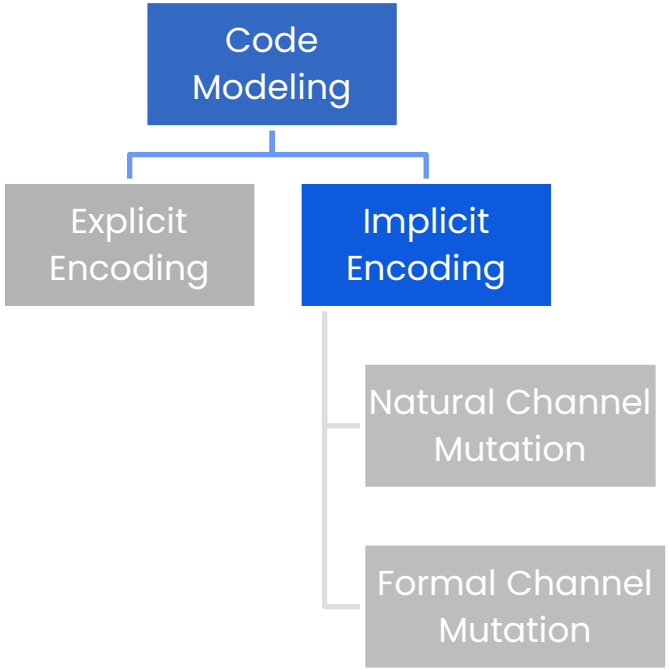
Pros

- Precision
- Guarantee
- Explainable
- Low Resource

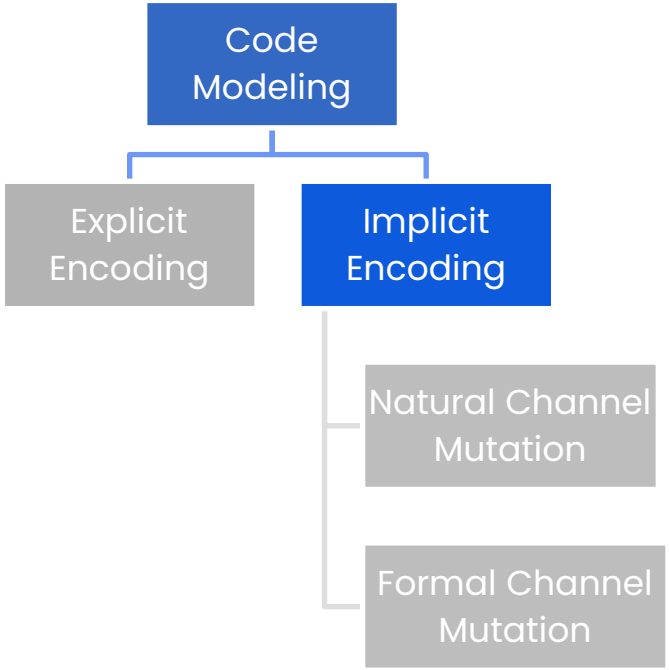
Cons

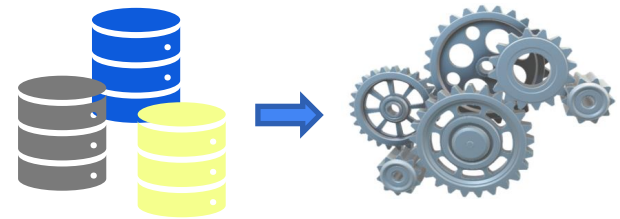
- Model design overhead
- Transferability

Implicit Encoding

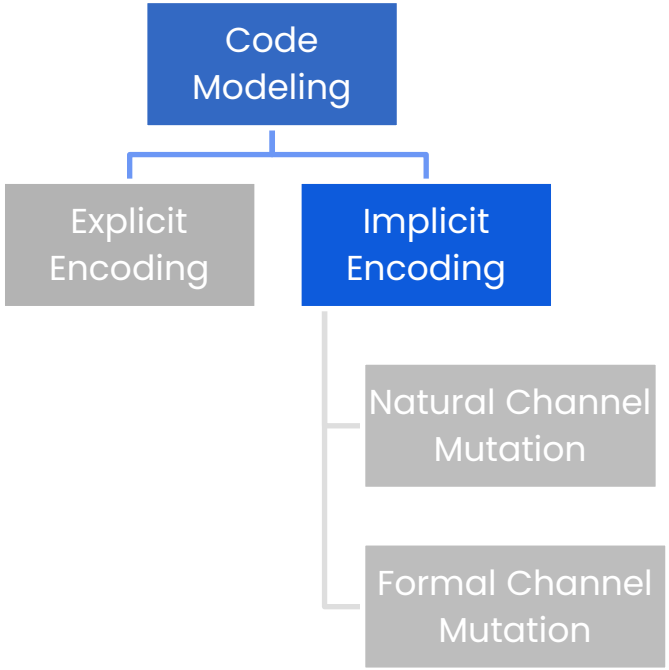


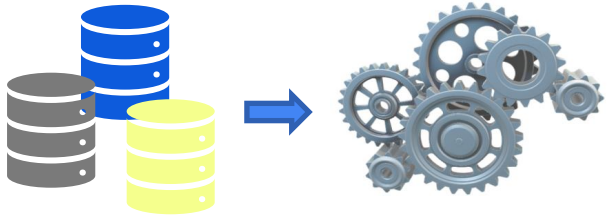
Implicit Encoding





Implicit Encoding





Large Data Corpus

```
printf [MASK] "Username: " ) ;
gets ( username ) ;
if ( [MASK]( username ) ) {
    allow = 1;
}
if ( allow != 0 ) [MASK]
   privilegedAction ( [MASK] ;
}
```

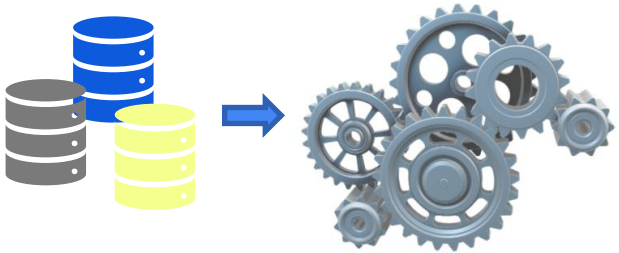
Corrupted Input Code

```
printf ( "Username: " ) ;
gets ( username ) ;
if ( gets( username ) ) {
    allow = 1;
}
if ( allow != 0 ) {
   privilegedAction ( ) ;
}
```

Regenerated Correct Code

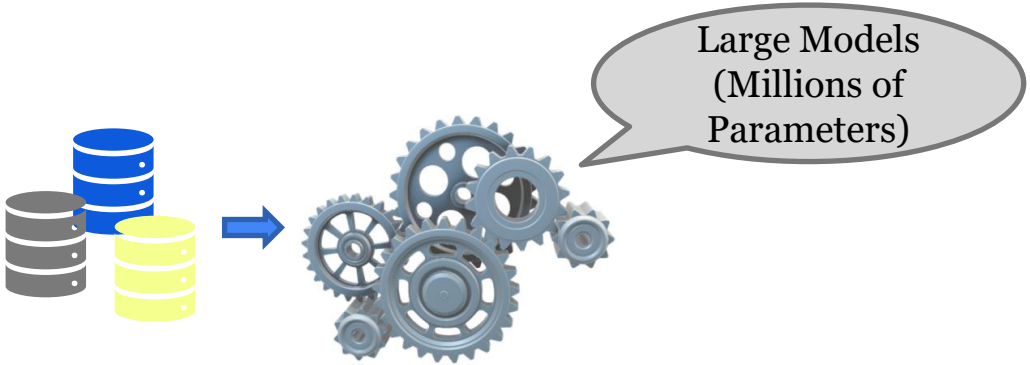
[11] CodeBERT – Feng et. al. 2019
[16] GraphCodeBERT – Guo et. al. 2020
[17] CodeX – Chen et. al. 2021
[18] CodeT5 – Wang et. al. 2021

Implicit Encoding - Pretraining



[17] CodeX – Chen et. al. 2021
[21] Github Copilot
[22] Amazon CodeWhisperer

Implicit Encoding - Pretraining



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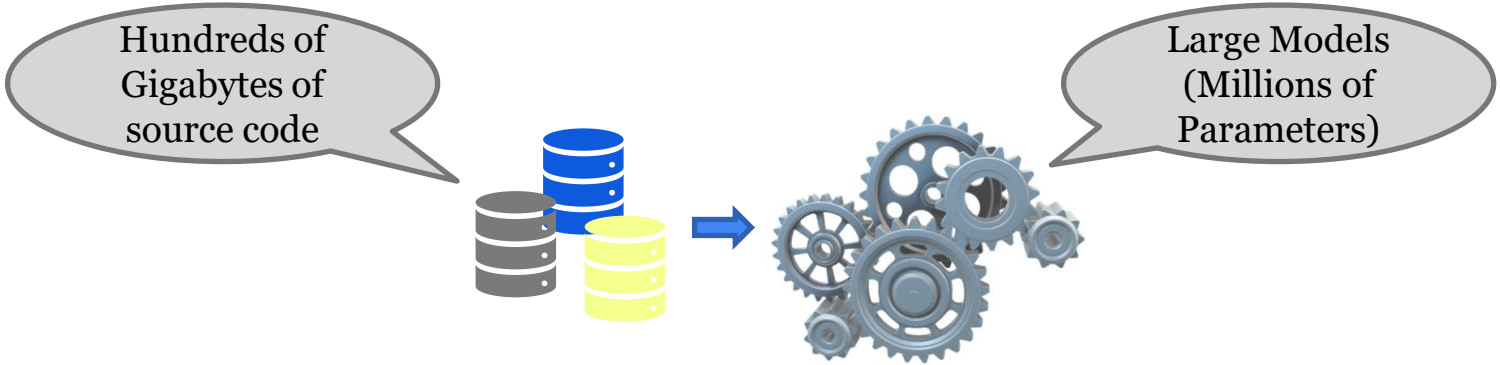

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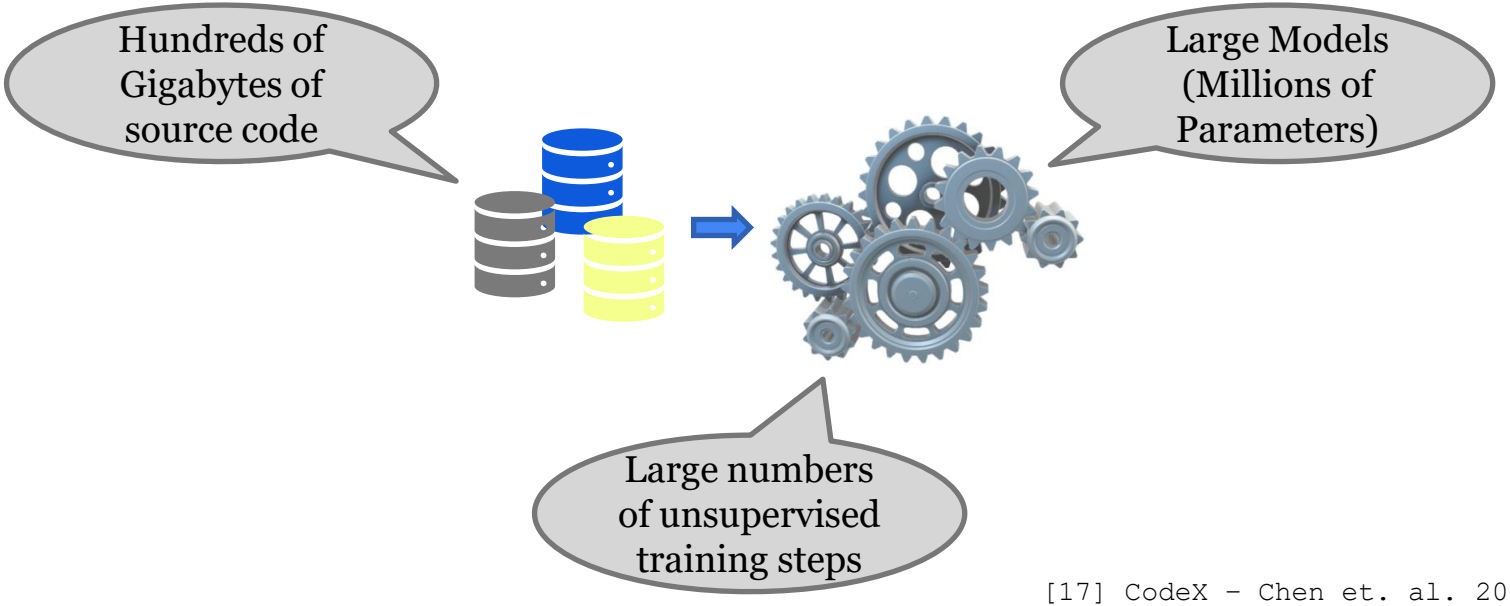

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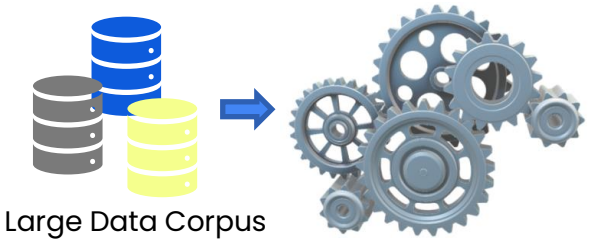
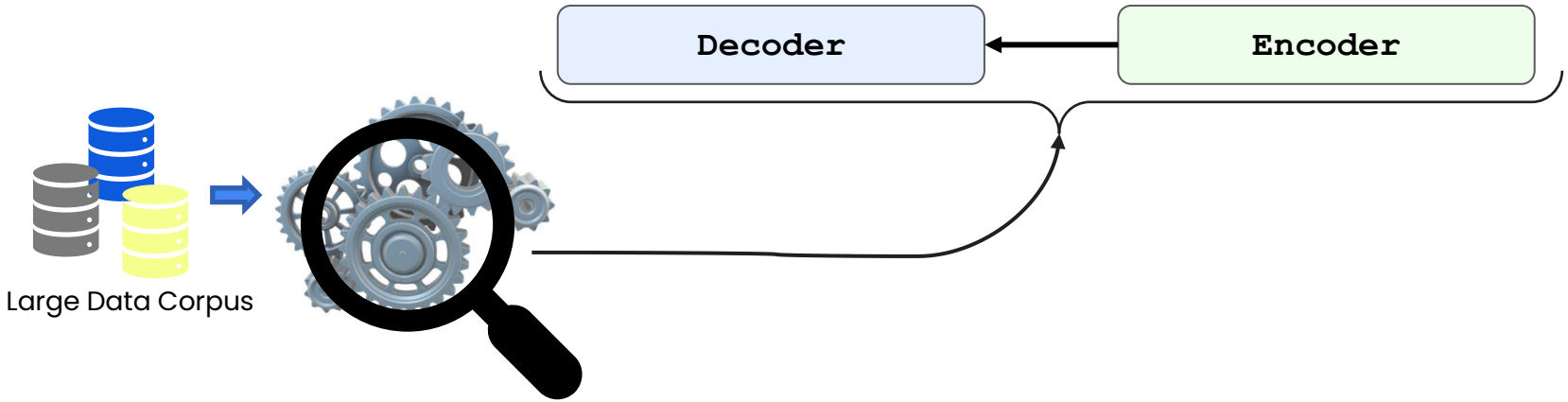


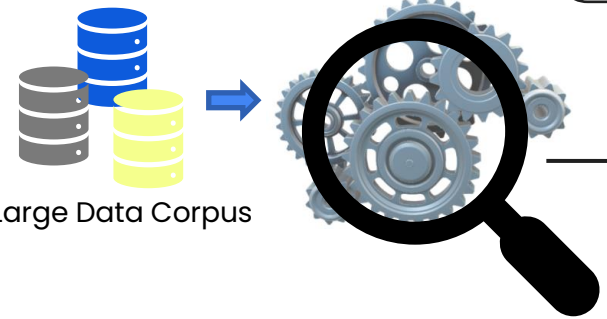
Implicit Encoding - Pretraining



Implicit Encoding - Pretraining

```
printf ( "Username: " ) ;
gets ( username ) ;
if ( gets( username ) ) {
    allow = 1 ;
}
if ( allow != 0 ) {
   privilegedAction ( ) ;
}
```

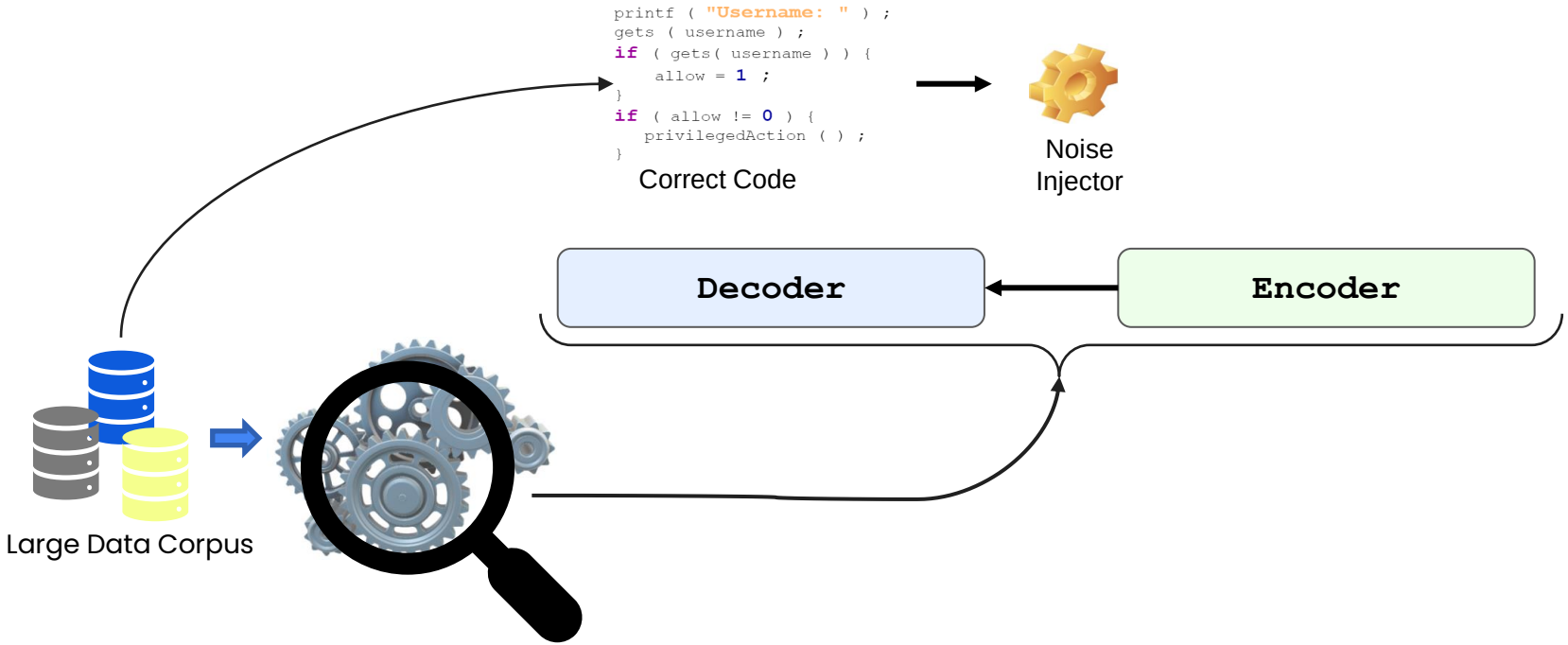
Correct Code



Large Data Corpus

Decoder ← **Encoder**

Implicit Encoding - Pretraining



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```
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}
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}
```

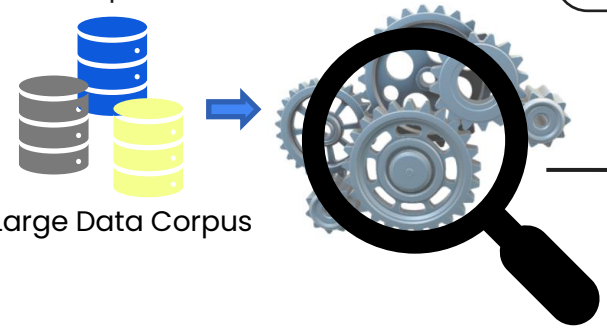
Correct Code

Noise Injector

```
printf ( "Username: " ) ;
gets ( username ) ;
if ( gets(
    allow = 1 ;
}
if ( allow  {
   privilegedAction ( ) ;
}
```

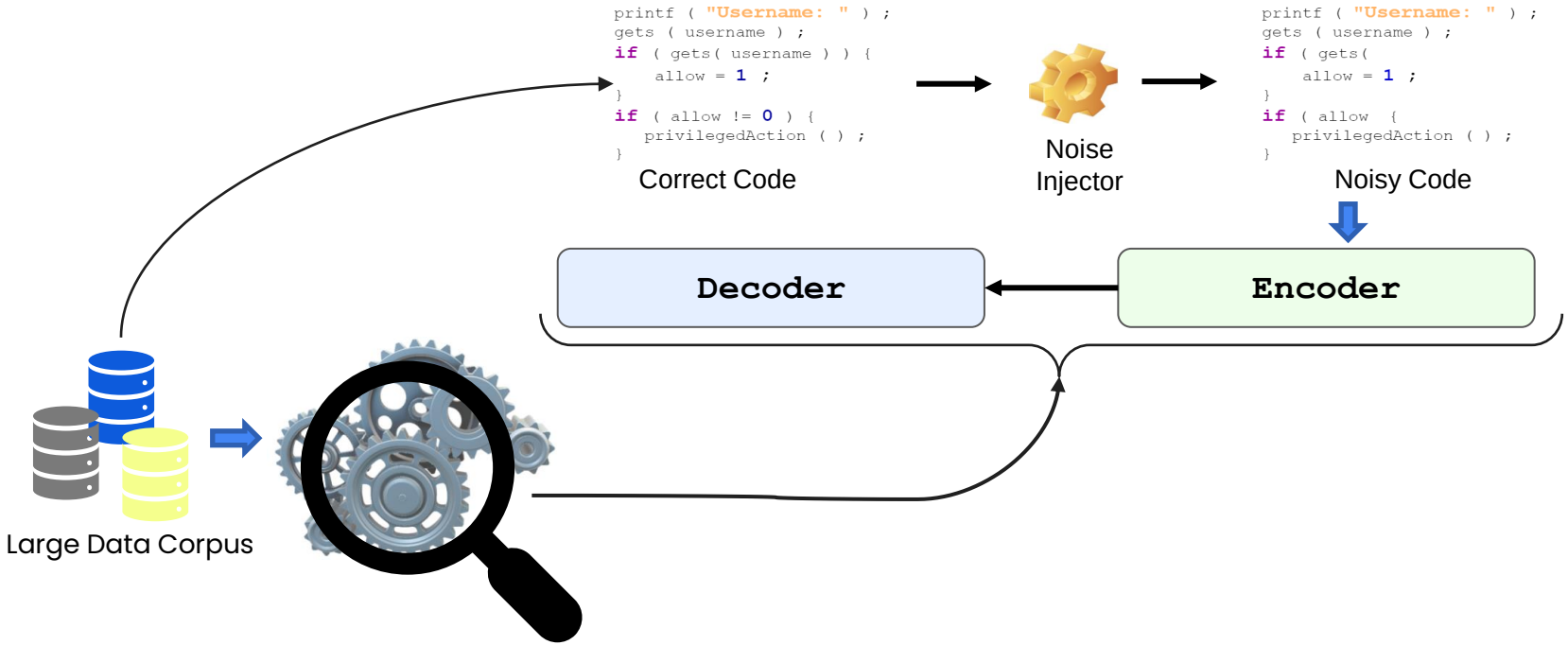
Noisy Code

Decoder ← **Encoder**

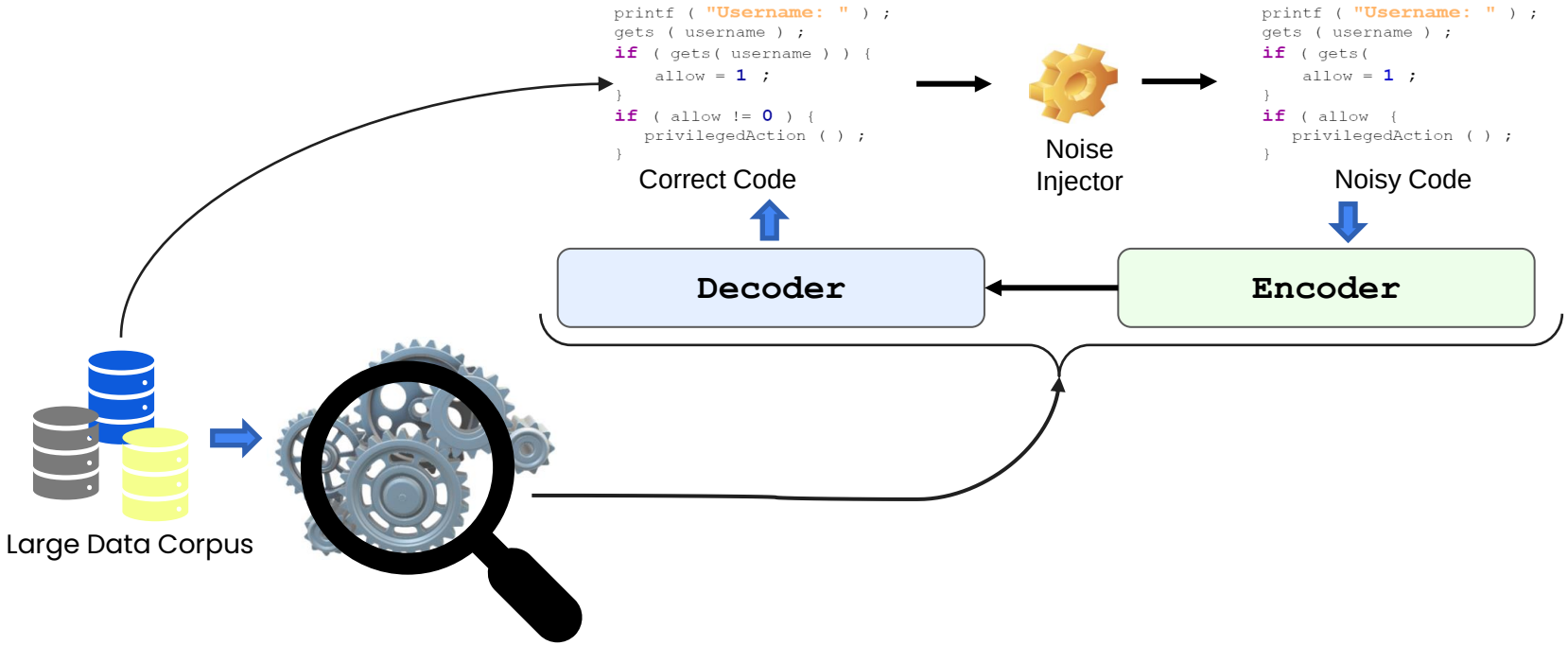


Large Data Corpus

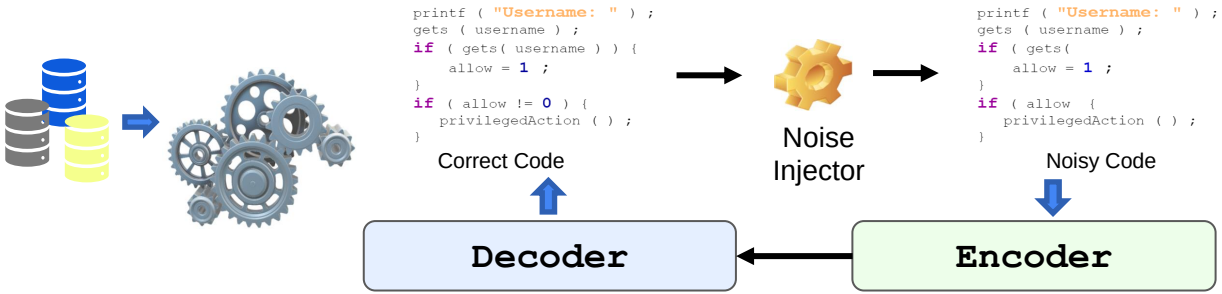
Implicit Encoding - Pretraining



Implicit Encoding - Pretraining



Implicit Encoding - Finetuning



Finetuning

Noise Injectors & Dual Channel Hypothesis for Source Code [19]

```
printf ( "Username: " ) ;
gets ( username ) ;
if ( gets( username ) ) {
    allow = 1 ;
}
if ( allow != 0 ) {
   privilegedAction ( ) ;
}
```

Correct Code

Noise Injector

```
printf ( "Username: " ) ;
gets ( username ) ;
if ( gets(
    allow = 1 ;
}
if ( allow  {
   privilegedAction ( ) ;
}
```

Noisy Code

Noise Injectors & Dual Channel Hypothesis for Source Code [19]

```
printf ( "Username: " ) ;
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```

Correct Code


```
printf ( "Username: " ) ;
gets ( username ) ;
if ( gets(
    allow = 1 ;
}
if ( allow  {
   privilegedAction ( ) ;
}
```

Noisy Code

Noise Injectors & Dual Channel Hypothesis for Source Code [19]

```
printf ( "Username: " ) ;
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if ( gets( username ) ) {
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}
if ( allow != 0 ) {
   privilegedAction ( ) ;
}
```

Correct Code


```
printf ( "Username: " ) ;
gets ( username ) ;
if ( gets(
    allow = 1 ;
}
if ( allow  {
   privilegedAction ( ) ;
}
```

Noisy Code

```
#include <stdio.h>
int main () {
    char username[8];
    int allow = 0;
    printf("Username: ");
    gets(username);
    if (grantAccess(username)) {
        allow = 1;
    }
    if (allow != 0) {
        privilegedAction();
    }
    return 0;
}
```

Natural Channel [19, 20]

Noise Injectors & Dual Channel Hypothesis for Source Code [19]

```
printf ( "Username: " ) ;
gets ( username ) ;
if ( gets( username ) ) {
    allow = 1 ;
}
if ( allow != 0 ) {
   privilegedAction ( ) ;
}
```

Correct Code

Noise Injector

```
printf ( "Username: " ) ;
gets ( username ) ;
if ( gets(
    allow = 1 ;
}
if ( allow  {
   privilegedAction ( ) ;
}
```

Noisy Code

```
1  #include <stdio.h>
2  int main () {
3      char username[8];
4      int allow = 0;
5      printf("Username: ");
6      gets(username);
7      if (grantAccess(username)) {
8          allow = 1;
9      }
10     if (allow != 0) {
11         privilegedAction();
12     }
13     return 0;
14 }
```

Natural Channel [19, 20]

```
1  #include <stdio.h>
2  int main () {
3      char username[8];
4      int allow = 0;
5      printf("Username: ");
6      gets(username);
7      if (grantAccess(username)) {
8          allow = 1;
9      }
10     if (allow != 0) {
11         privilegedAction();
12     }
13     return 0;
14 }
```

Formal Channel

Noise Injectors & Dual Channel Hypothesis for Source Code [19]

```
printf ( "Username: " ) ;
gets ( username ) ;
if ( gets( username ) ) {
    allow = 1 ;
}
if ( allow != 0 ) {
   privilegedAction ( ) ;
}
```

Correct Code

Noise Injectors

```
printf ( "Username: " ) ;
gets ( username ) ;
if ( gets(
    allow = 1 ;
}
if ( allow  {
   privilegedAction ( ) ;
}
```

Noisy Code

```
1  #include <stdio.h>
2  int main () {
3      char username[8];
4      int allow = 0;
5      printf("Username: ");
6      gets(username);
7      if (grantAccess(username)) {
8          allow = 1;
9      }
10     if (allow != 0) {
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12     }
13     return 0;
14 }
```

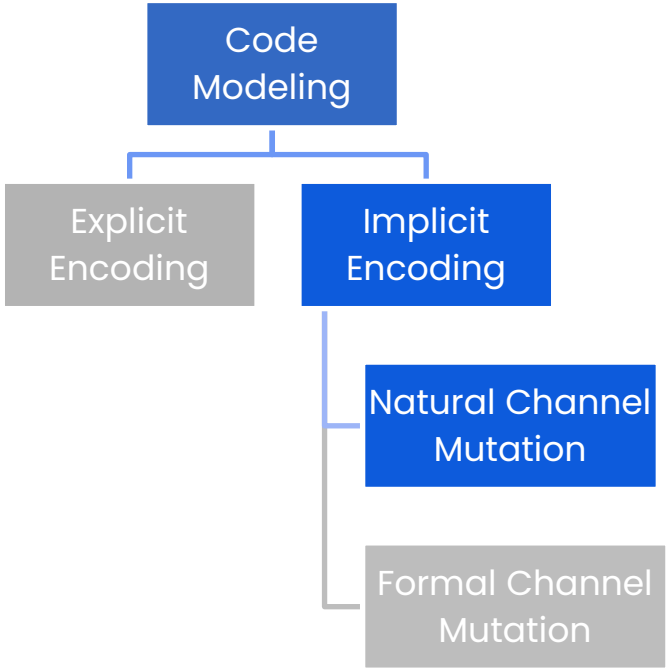
Natural Channel [19, 20]

```
1  #include <stdio.h>
2  int main () {
3      char username[8];
4      int allow = 0;
5      printf("Username: ");
6      gets(username);
7      if (grantAccess(username)) {
8          allow = 1;
9      }
10     if (allow != 0) {
11         privilegedAction();
12     }
13     return 0;
14 }
```

Formal Channel

[19] Casalanuovo et. al. 2020
[20] Karampatsis et. al. 2020

Natural Channel Mutation

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   privilegedAction ( ) ;
}
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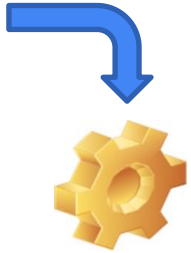

Mutator

```
printf [MASK] "Username: " ) ;
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Unified Pre-training for Program Understanding and Generation (PLBART)

NAACL - 2021

CS@CU

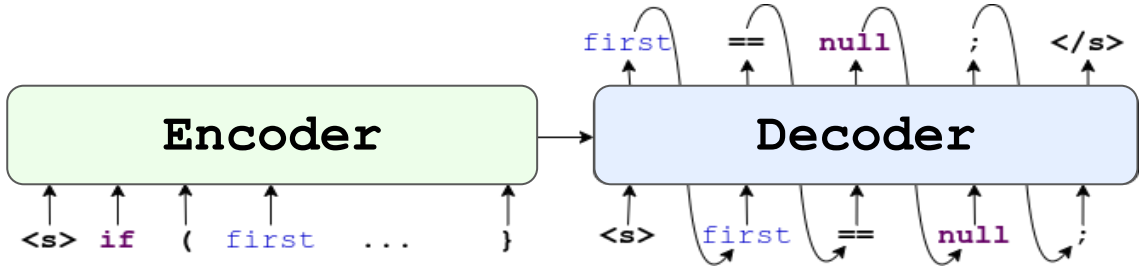
Findings

PL properties can be learned from large scale source- code dataset.

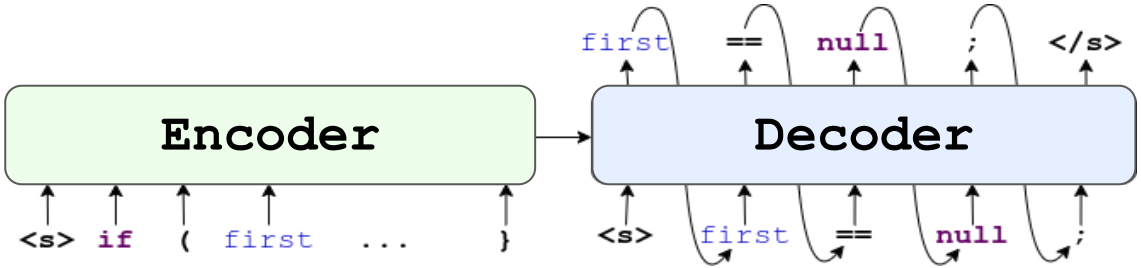
Contribution

Developed large scale pre-trained models for different SE tasks.

PLBART – What Is It?



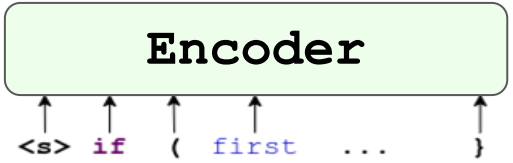
PLBART – What Is It?



- Transformer Based Models
- 6 Encoder Layer, 6 Decoder Layer
- 12 attention heads

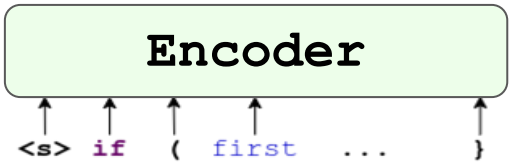
PLBART – Components

PLBART – Components



1. **Read** Code.
2. **Understands** Code.
3. **Reason** about any errors in code.
4. **Learns** robust **representation**

PLBART – Components



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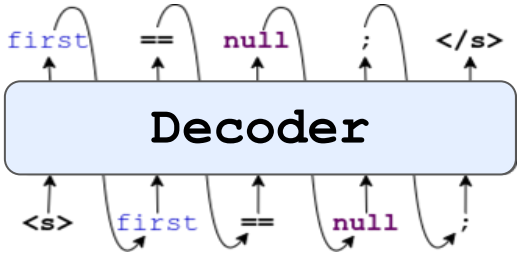

1. Generate Code.
2. Learns **Coding Patterns**.

PLBART – Pretraining

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Correct Code

Noise Injector

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Noisy Code

Decoder ← **Encoder**

PLBART

PLBART – Pretraining

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Decoder ← **Encoder**

PLBART

Token Masking

Token Deletion

Token Infilling

PLBART – Jointly Learning to Understand and Generate

Token Masking

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PLBART – Pretraining

- Noise Properties
  - Mutate Natural Channel
  - Likely to Break Syntax

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- Training Objectives
  - Generate the whole code.
  - Learns syntax implicitly
  - Learn Coding Patterns.

- Multi-lingual Training
  - Java
  - Python
  - NL from Stack overflow

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PLBART

Evaluation

Downstream Tasks

Task	Dataset	Language	Train	Valid	Test
Summarizaion	Husain et al. (2019)	Ruby	24,927	1,400	1,261
		Javascript	58,025	3,885	3,291
		Go	167,288	7,325	8,122
		Python	251,820	13,914	14,918
		Java	164,923	5,183	10,955
		PHP	241,241	12,982	14,014
Generation	Iyer et al. (2018)	NL to Java	100,000	2,000	2,000
Translation	Code-Code (Lu et al., 2021)	Java to C#	10,300	500	1,000
		C# to Java	10,300	500	1,000
	Program Repair (Tufano et al., 2019)	Java_{small}	46,680	5,835	5,835
		Java_{medium}	52,364	6,545	6,545
Classification	Vulnerability Detection (Zhou et al., 2019)	C/C++	21,854	2,732	2,732
	Clone Detection (Wang et al., 2020)	Java	100,000	10,000	415,416

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Code Editing (Program Repair) Result

Dataset: Bugfix dataset, Tufano *et. al.* 2019 [7] – Abstract Edit
Metric: EM (exact match) in Top-1 position

```
Small - Upto 50 Tokens
Medium - 51-100 tokens
```

Methods	Small	Medium
	EM	EM
Naive Copy	0	0
Seq2Seq	10.00	2.50
Transformer	14.70	3.70
CodeBERT	16.40	5.16
GraphCodeBERT	17.30	**9.10**
PLBART	**19.21**	8.98

```
    if (
-           newJson.charAt(1) != wrappingQuote
+           !jsonObject.isEmpty() &&
+           (newJson.charAt(1) != wrappingQuote)
    ){
```

```
// Guidance: fix problem which occurred when
// the resulting json is empty ...
```

```
    if (
-           newJson.charAt(1) != wrappingQuote
+           !jsonObject.isEmpty() &&
+           (newJson.charAt(1) != wrappingQuote)
    ){
```

Developers Guidance

```
// Guidance: fix problem which occurred when
// the resulting json is empty ...

private String generateResultingJsonString(
      char wrappingQuote, Map<String, Object>jsonMap){
    JsonObject jsonObject = new JSONObject(jsonMap);
    String newJson = jsonObject.toJSONString(LT_COMPRESS);
    if (
-         newJson.charAt(1) != wrappingQuote
+         !jsonObject.isEmpty() &&
+         (newJson.charAt(1) != wrappingQuote)
    ){
    return replaceUnescaped(
        newJson, newJson.charAt(1), qrappingQuote);
    }
    return newJson;
}
```

✅ **Developers Guidance**

✅ **Context**

```
// Guidance: fix problem which occurred when
// the resulting json is empty ...

private String generateResultingJsonString(
      char wrappingQuote, Map<String, Object>jsonMap){
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    return replaceUnescaped(
        newJson, newJson.charAt(1), qrappingQuote);
    }
    return newJson;
}
```

✅ **Developers Guidance**

✅ **Context**

MODIT : Multi-Modal Learning of Editing Source Code

- ASE 2021

Findings

Developer Guidance and Context of Edit are very important for Automated Code Editing.

Contribution

Leveraging multiple information modalities to Automate Code editing, and identification of best way of processing such modalities.

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MODIT : Multi Modal Code Editing (pipeline)

Input Modalities

Modality 1: Code to be edited

```
newJson.charAt(1) != wrappingQuote
```

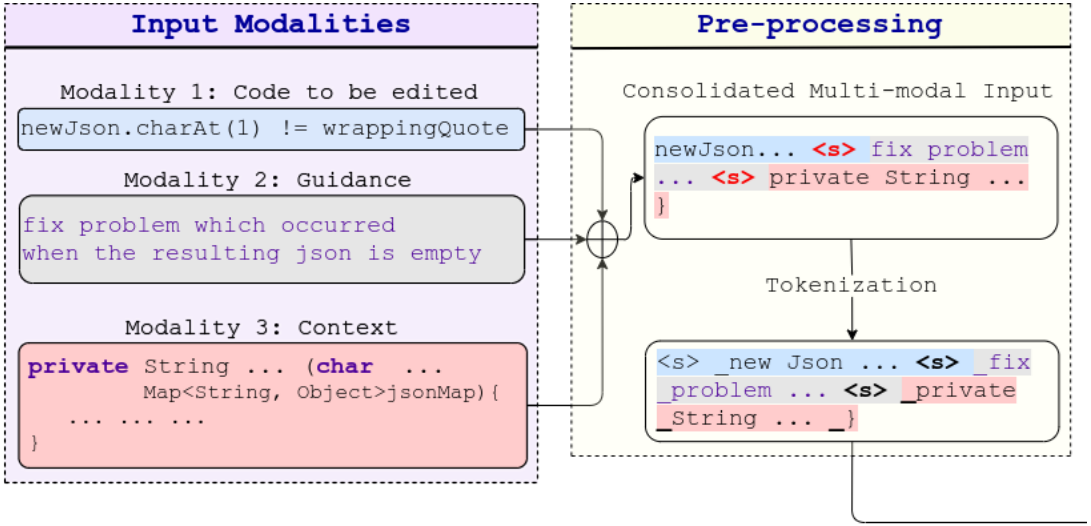
Modality 2: Guidance

```
fix problem which occurred
when the resulting json is empty
```

Modality 3: Context

```
private String ... (char  ...
        Map<String, Object>jsonMap){
   ... ... ...
}
```

MODIT : Multi Modal Code Editing (pipeline)



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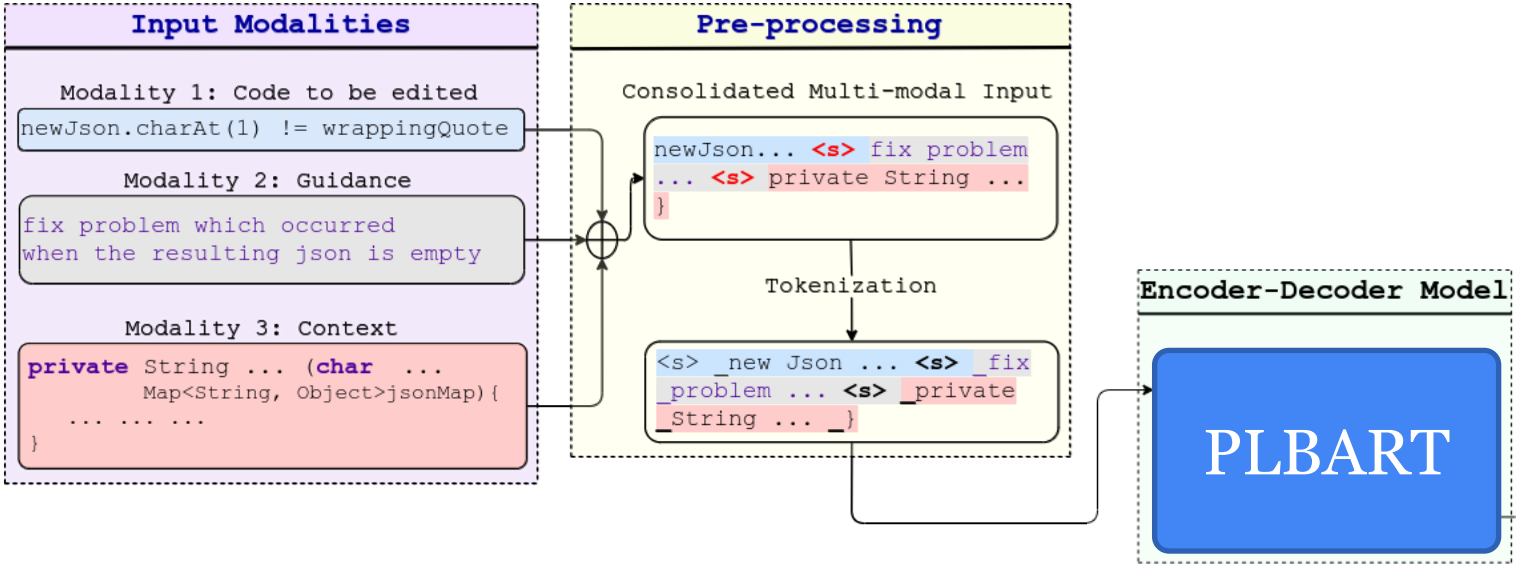

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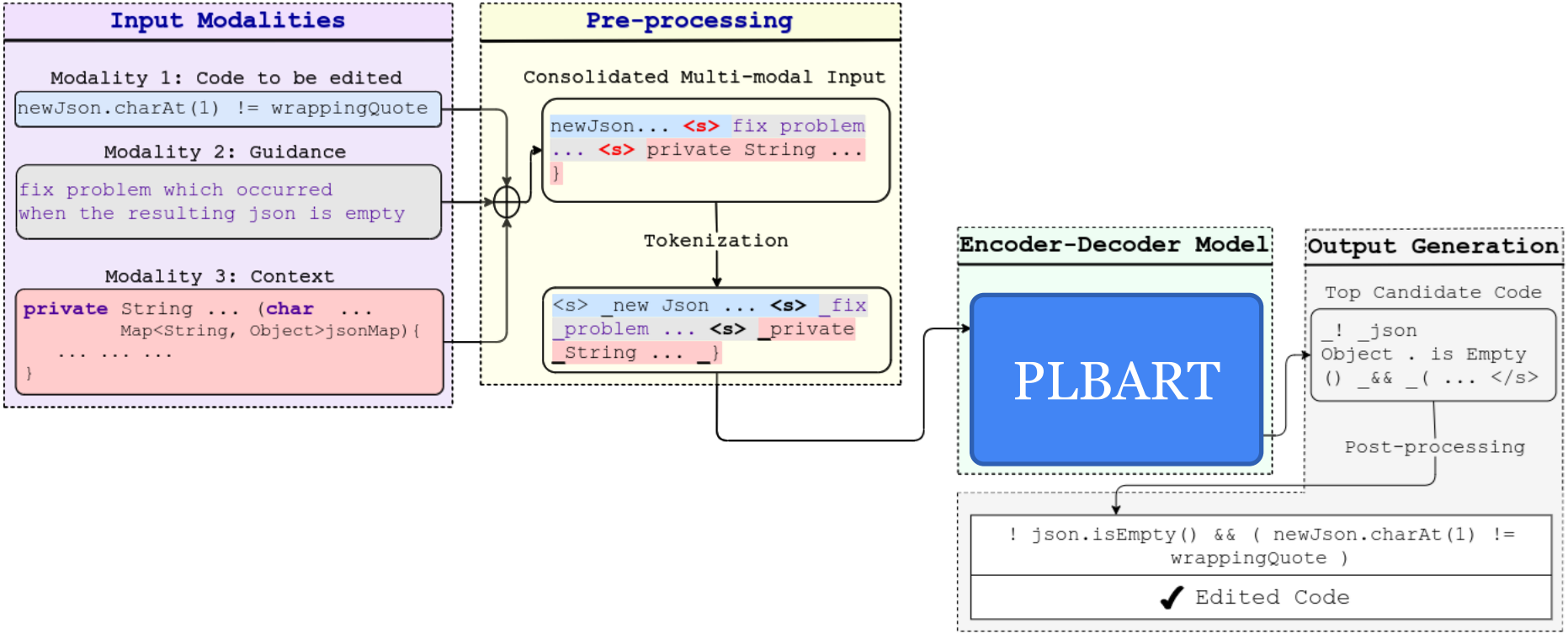

MODIT

Evaluation

Experiments

Dataset (Tufano et. al. ICSE 2019 [7]) – Concrete Edits

Dataset	Avg. Tokens	Avg. Change Size*	Avg. tokens in Guidance	# examples		
				Train	Valid	Test
$B2F_s$	32.27	7.39	11.55	46628	5828	5831
$B2F_m$	74.65	8.83	11.48	53324	6542	6538

* Change size measured as token edit distance.

MODIT : Result

Training Type	Model Name	# of params (M)	Multi-Modal	Accuracy (%)	
				$B2F_s$	$B2F_m$
From Scratch	LSTM	82.89	✓	6.14	1.04
	Transformer-base	139.22	✓	11.18	6.61
	Transformer-large	406.03	✓	13.40	8.63
	CODIT	105.43	✗	6.53	4.79
Fine-tuned	CodeBERT	172.50	✗	24.28	16.76
			✓	26.05	17.13
	GraphCodeBERT	172.50	✗	24.44	16.85
			✓	25.67	18.31
	CodeGPT	124.44	✗	28.13	16.35
			✓	28.43	17.64
	MODIT (PLBART)	139.22	✗	26.67	19.79
			✓	**29.99**	**23.02**

Interesting Code Generated by PLBART

Interesting Code Generated by PLBART

PLBART generated

```
public int getCells(){
    Iterator<Character> i =
       cells.keySet().iterator();
    int size = 0;
    for ( ; i.hasNext() ; ) {
        Cell e = at(c);
        ...
    }
    return size;
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Better Code

```
public int getCells(){
    Iterator<Character> i =
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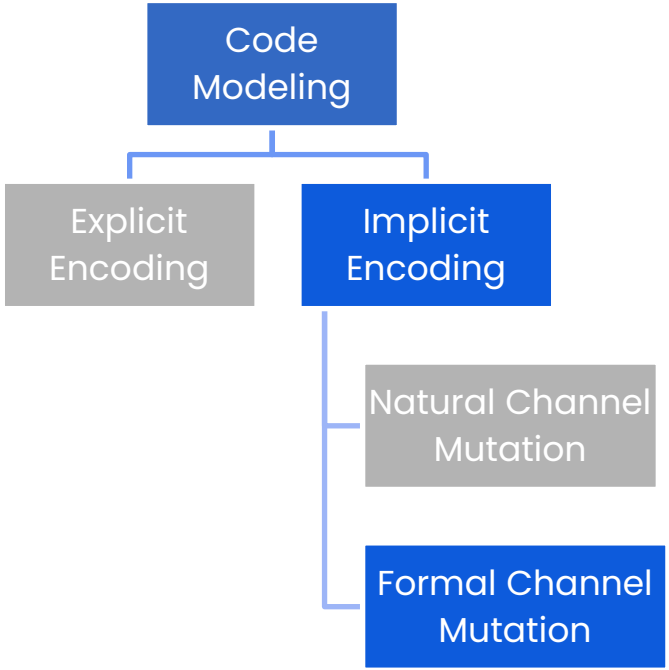
Formal Channel Mutation

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NatGen: Generative Pretraining by "Naturalizing" Source Code

- FSE 2022

Findings

Forcing a model to edit unnatural code to re-write in a more natural way embeds developers' natural way of writing code into the model.

Contribution

Designed a large-scale pretrained model which learned natural coding patterns from developers, with demonstrated higher performance in few shot code generation.

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NatGen: Generative pre-training by “Naturalizing” source code

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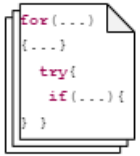
Write Semantic / Functional Equivalent Code in “More Natural” way

NatGen: Generative pre-training by “Naturalizing” source code



Natural Code

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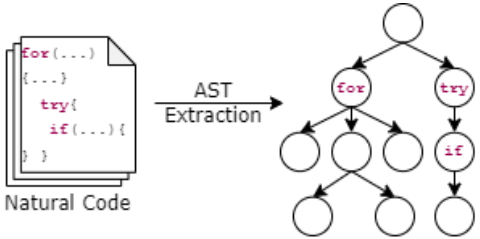

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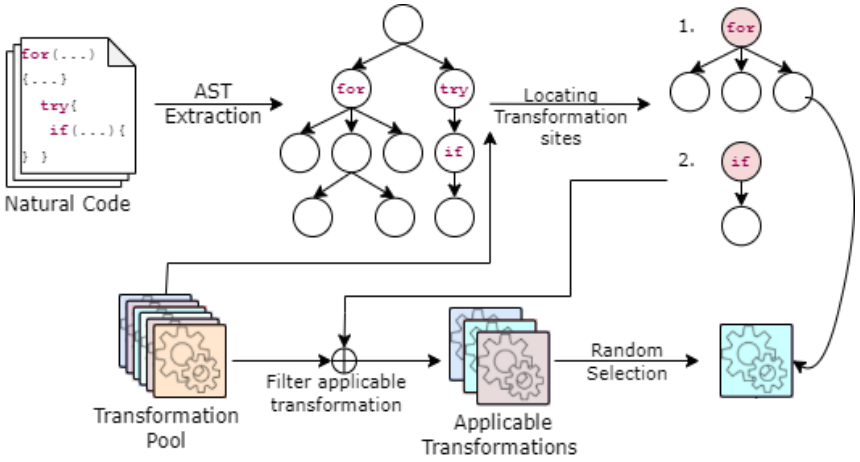

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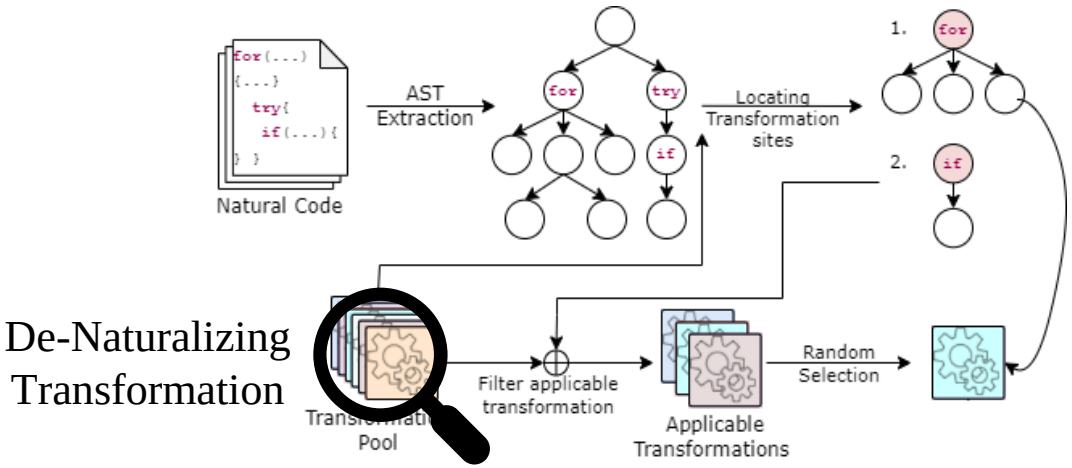

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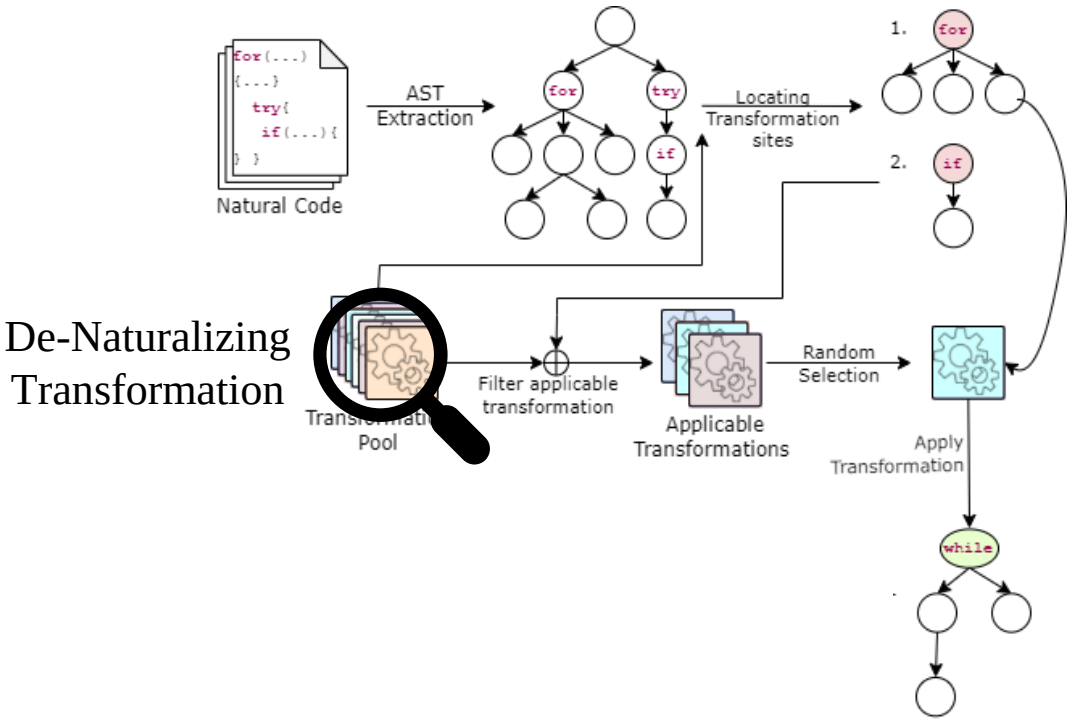

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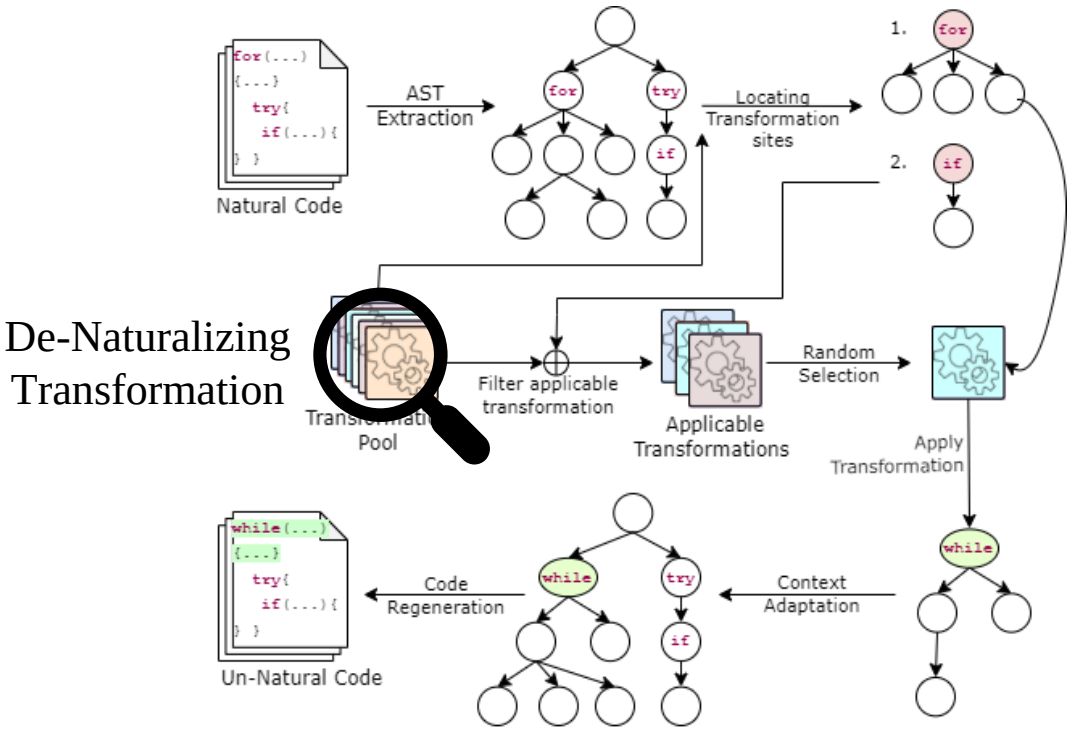

NatGen: De-Naturalizing Transformations

NatGen: De-Naturalizing Transformations

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public int getCells(){
    Iterator<Character> i =
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    int size = 0;
    while(size > 0) {
        Cell e = at(size);
    }
    while(i.hasNext()) {
        Cell e = at(c);
        ...
    }
    return size;
}
```

Dead Code Insertion

NatGen: De-Naturalizing Transformations

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        ...
    }
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}
```

Dead Code Insertion

```
- if (x > 0) {
-   Cell e = at(x);
- }
- else {
-    Cell c = at(x+1);
- }
+ Cell c = (x > 0)? at(x) : at(x+1);
```

Confusing Statements [17]

[21] Gopstein et. al. 2020

NatGen: De-Naturalizing Transformations

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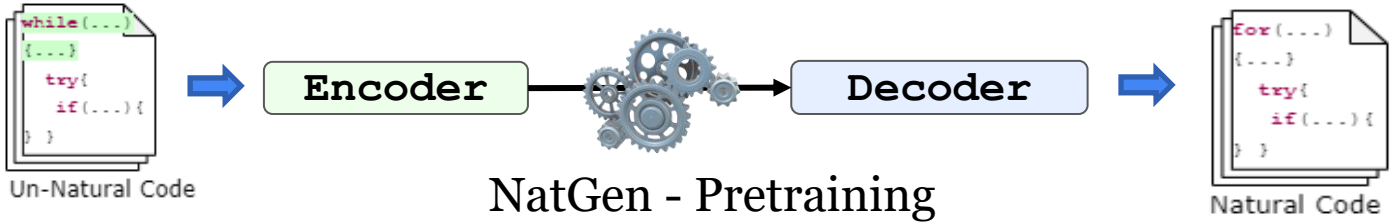
Confusing Statements [17]

```
- if ( x > 0 ) {
+ if ( 0 < x ) {
      Cell e = at(x);
}
```

Operand Swap

[21] Gopstein et. al. 2020

NatGen: Generative pre-training by “Naturalizing” source code



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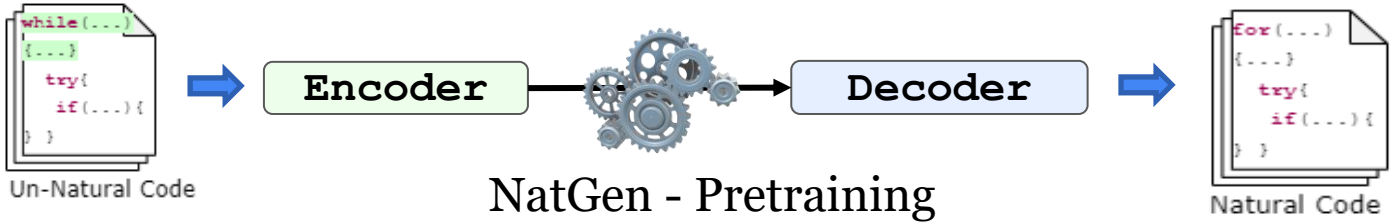
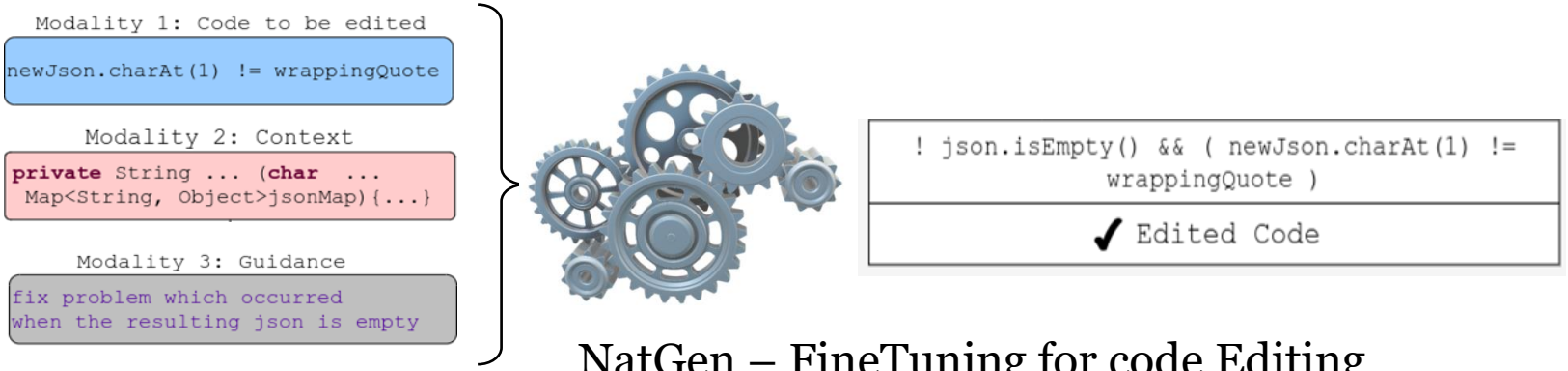


NatGen - Pretraining



NatGen – FineTuning for code Editing

NatGen

Evaluation

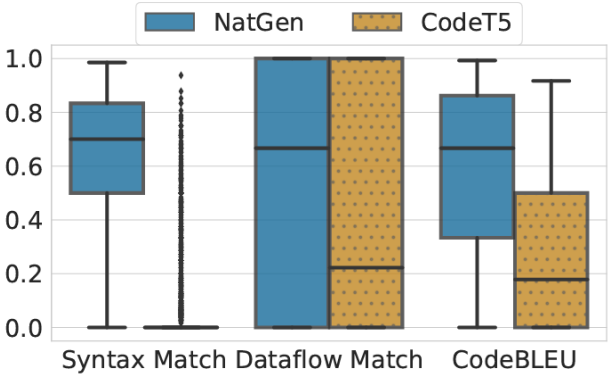
NatGen: Automated Code Editing Result

Approach	BugFix_{small}		BugFix_{medium}	
	Unimodal	**Multimodal**	**Unimodal**	**Multimodal**
MODIT	20.35	21.57	8.35	13.18
CodeT5	21.79	22.97	12.59	**14.94**
NatGen	**22.26**	**23.43**	**13.32**	14.93

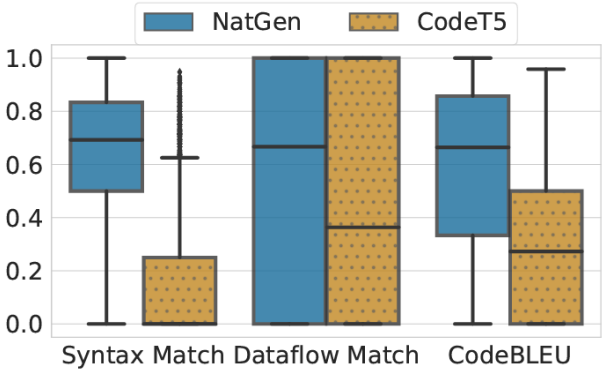
BugFix dataset proposed by Tufano et al. (ICSE 2019) [7]

Exact Match accuracy (%) at Top 1 generated edit.

NatGen: Automated Code Editing Result

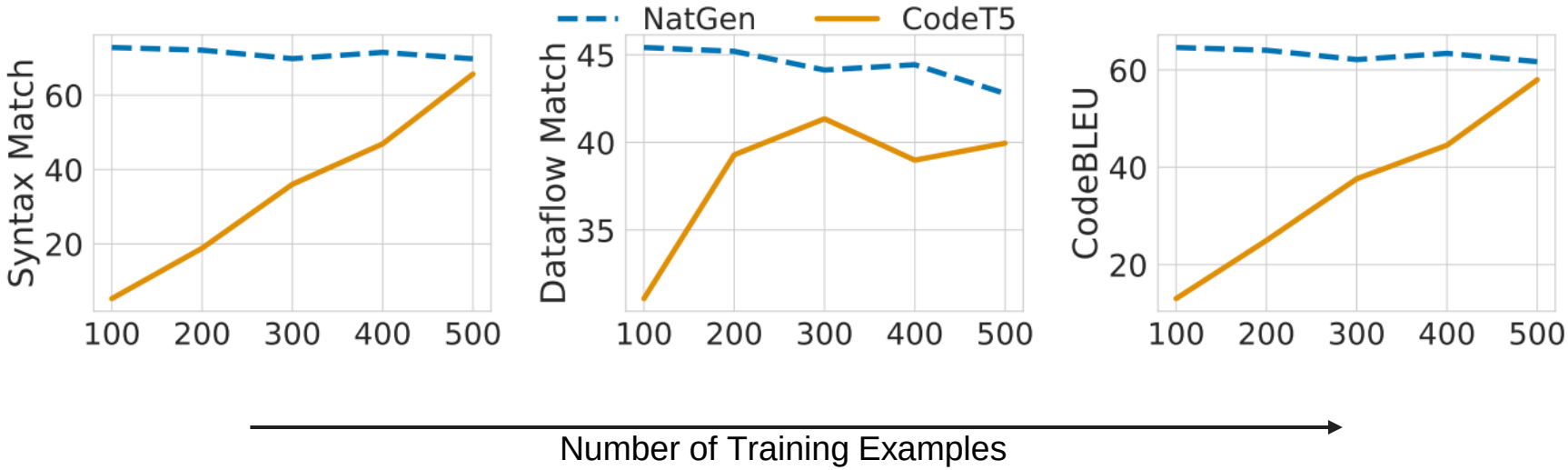


Zero-Shot

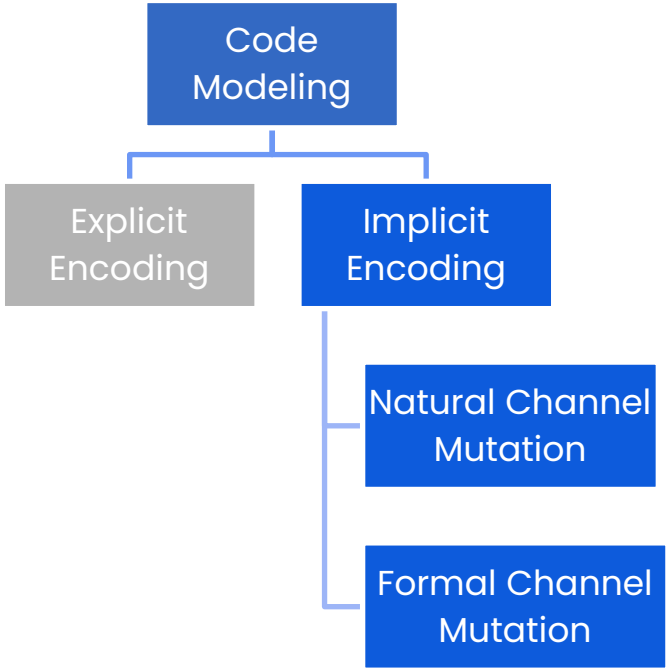


Few-shot (200 training examples)

NatGen: Automated Code Editing Result



Explicit Encoding – Take Aways



Pros

- Little overhead
- Unsupervised
- Transferable

Cons

- No Guarantee
- Potential Bias from Mutation
- Pretraining needs massive resource

Dissertation Summary

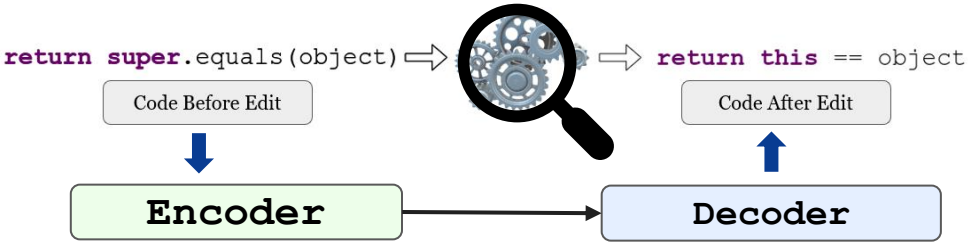
```
return super.equals(object)
```

Code Before Edit

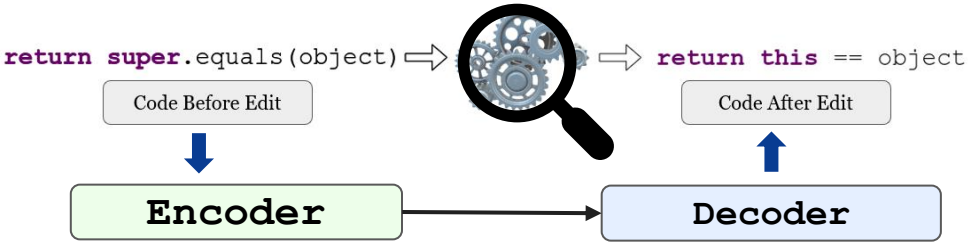
```
return this == object
```

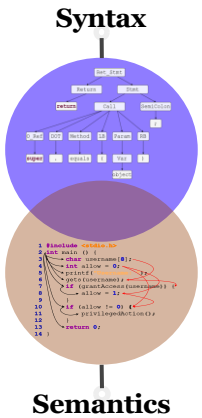
Code After Edit

Dissertation Summary

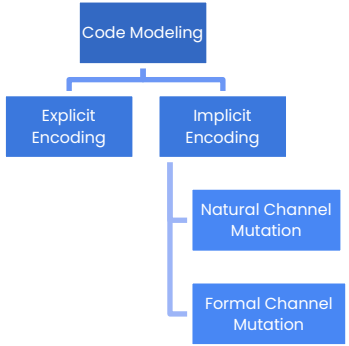


Dissertation Summary

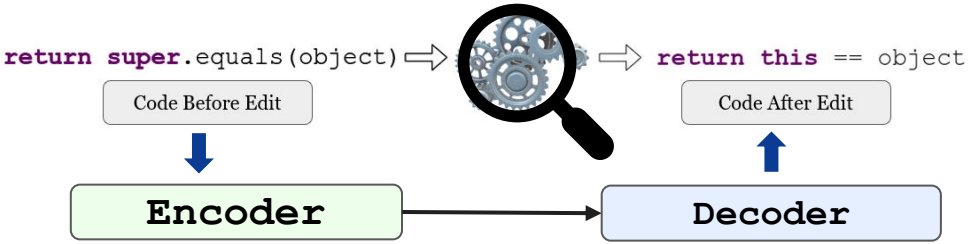


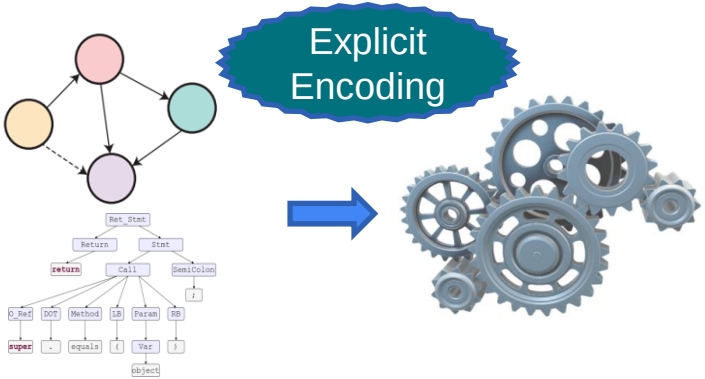


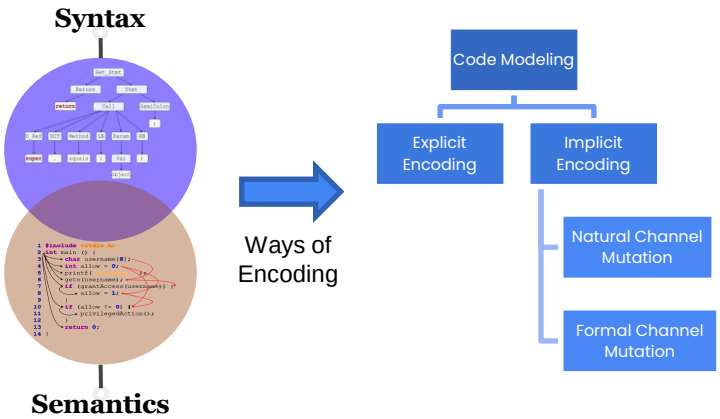
Ways of Encoding



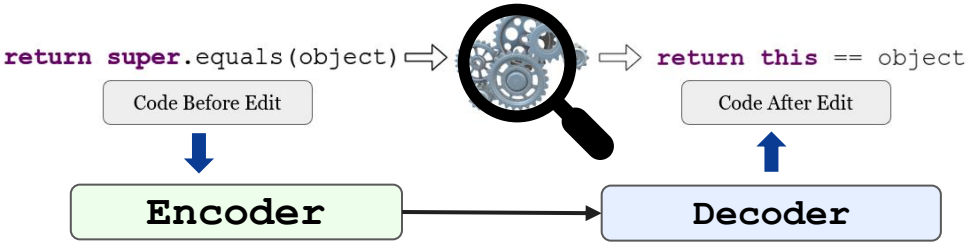
Dissertation Summary

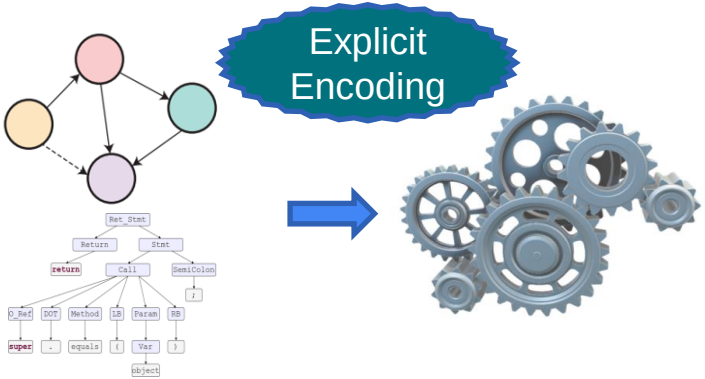


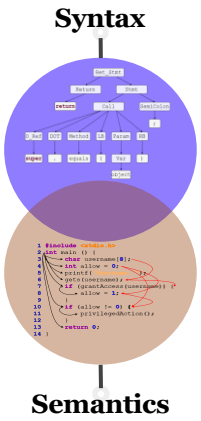




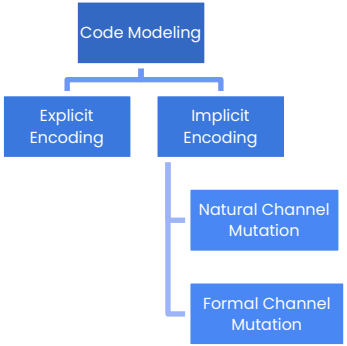
Dissertation Summary

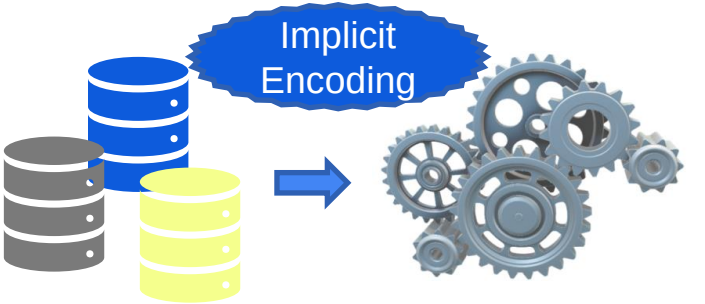






Ways of Encoding





Large Data Corpus

List of Publications

1. **NatGen: Generative pre-training by" Naturalizing" source code** - S Chakraborty, T Ahmed, Y Ding, P Devanbu, B Ray. The ACM Joint European Software Engineering Conference and Symposium on the Foundations of Software Engineering (ESEC/FSE 2022).
2. Towards Learning (Dis)-Similarity of Source Code from Program Contrasts - Y Ding, L Buratti, S Pujar, A Morari, B Ray, S Chakraborty Proceedings of the 60th Annual Meeting of the Association for Computational Linguistics (ACL'22).
3. **On Multi-Modal Learning of Editing Source Code** - S Chakraborty, B Ray 2021 36th IEEE/ACM International Conference on Automated Software Engineering (ASE'21).
4. Retrieval Augmented Code Generation and Summarization - MR Parvez, WU Ahmad, S Chakraborty, B Ray, KW Chang Findings of the Association for Computational Linguistics 2021 (ENMLP).
5. **Deep learning-based vulnerability detection: Are we there yet?** - S Chakraborty, R Krishna, Y Ding, B Ray IEEE Transactions on Software Engineering (TSE'21).
6. **Unified Pre-training for Program Understanding and Generation** - WU Ahmad, S Chakraborty, B Ray, KW Chang Annual Conference of the North American Chapter of the Association for Computational Linguistics (NAACL'21).
7. **CODIT: Code editing with tree-based neural models** - S Chakraborty, Y Ding, M Allamanis, B Ray IEEE Transactions on Software Engineering (TSE'20).
8. A transformer-based Approach for Source Code Summarization - W Ahmad, S Chakraborty, B Ray, KW Chang Association for Computational Linguistics (ACL'20).
9. Toward optimal selection of information retrieval models for software engineering tasks - MM Rahman, S Chakraborty, G Kaiser, B Ray 2019 19th International Working Conference on Source Code Analysis and Maintenance (SCAM'19).
10. Building language models for text with named entities - MR Parvez, S Chakraborty, B Ray, KW Chang 56th Annual Meeting of the Association for Computational Linguistics (ACL'18).
11. Which similarity metric to use for software documents? A study on information retrieval-based software engineering tasks - MM Rahman, S Chakraborty, B Ray Proceedings of the 40th International Conference on Software Engineering (ICSE'18).

My Research Applications

Programming Language Processing

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NeuralCodeSum (**ACL'20**), PLBART (**NAACL'21**)

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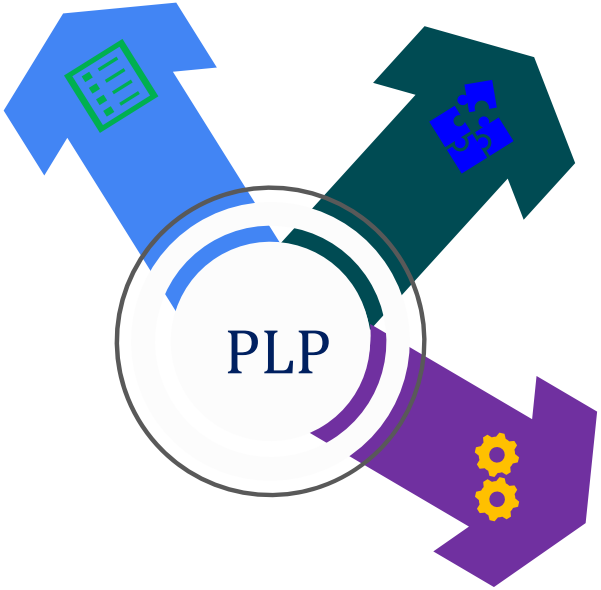

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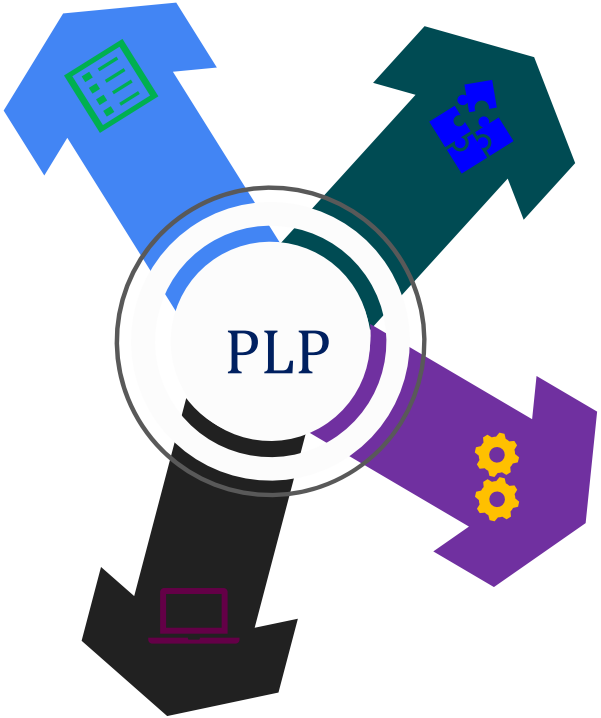

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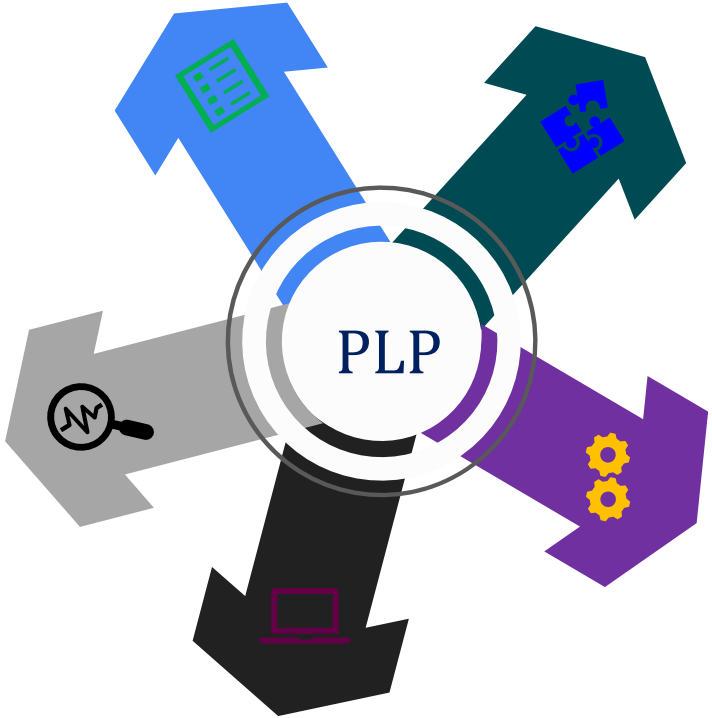
Code Search and Synthesis
RedCoder (**EMNLP'21**), CodePanda (W.I.P)



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Future Plan (Short Term Goal)

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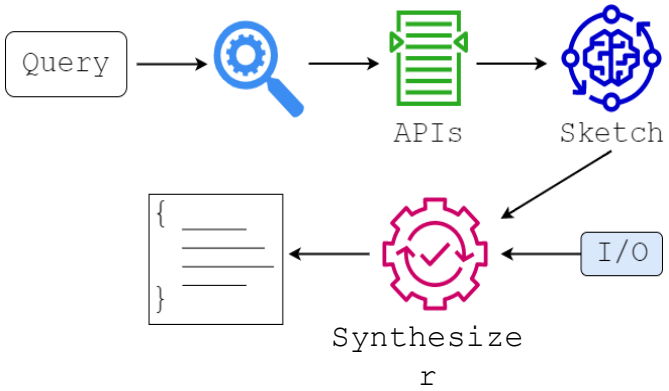
- API driven Program Synthesis



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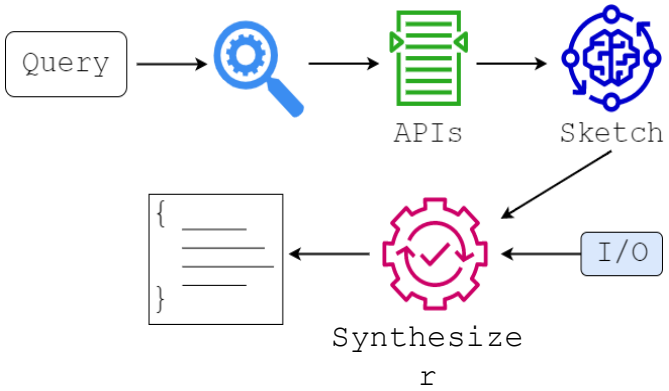
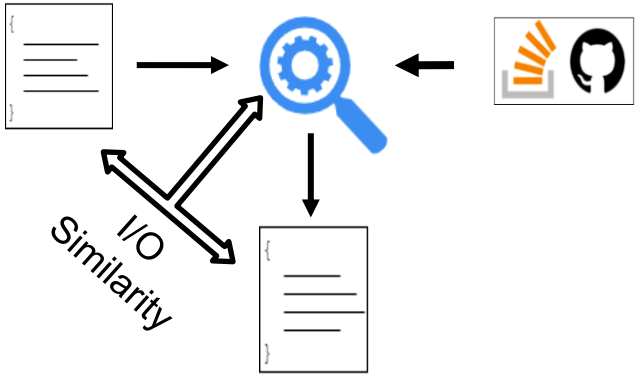


- Improving Semantic Code Search with RL



Future Plan (Short Term Goal)

- Learning Code Syntax and Semantics with Reinforcement Learning (RL)

```
void foo(Scanner sc) {
    String s = "";
    while(sc.hasNext().get()){
        s += sc.nextInt();
    }
    return s;
}
```

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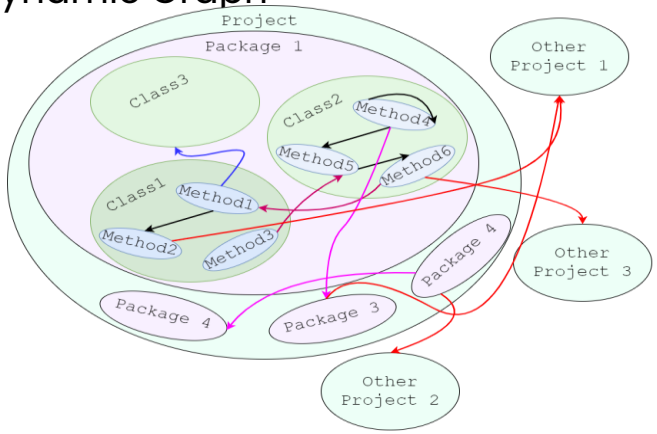
```

- Representing Code Context as Dynamic Graph



Future Plan (Long Term Goal)

Future Plan (Long Term Goal)

- Code Generation

Formal Analysis

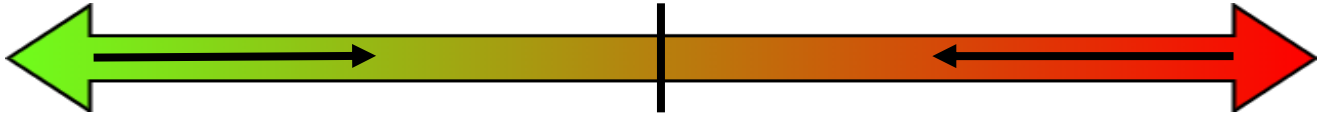
- ✓ **Guarantee** for the Analysis
- ✗ Noise Intolerant

Probabilistic models

- ✓ **Scalable** and **Transferrable**
- ✗ No theoretical Guarantee

Future Plan (Long Term Goal)

- Code Generation



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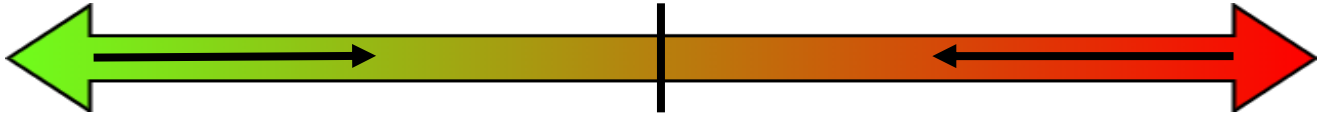
Future Plan (Long Term Goal)

- Code Generation



Formal Analysis

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Future Plan (Long Term Goal)

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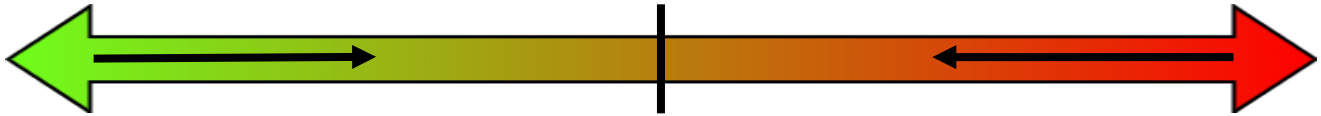

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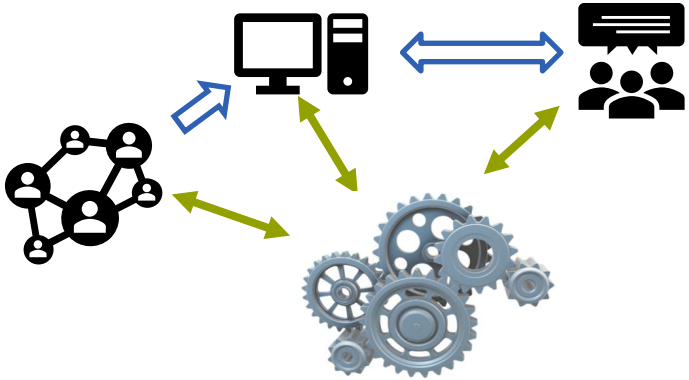

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Adviser

Wasi Ahmad
UCLA / Amazon

Miltos Allanmanis
MSR

Kai-Wei Chang
UCLA

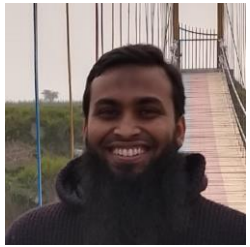
Prem Devanbu
UC Davis

Yangruibo Ding
Columbia

Gail Kaiser
Columbia University

Rahul Krishna
Columbia / IBM

Toufiq Parag
UC Davis



Rizwan Parvez
UCLA

Masudur Rahman
Uva/Purdue

References

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[2] Meng, Na, Miryung Kim, and Kathryn S. McKinley. "LASE: locating and applying systematic edits by learning from examples." 2013 35th International Conference on Software Engineering (ICSE). IEEE, 2013.

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[6] Tufano, Michele, et al. "An empirical investigation into learning bug-fixing patches in the wild via neural machine translation." Proceedings of the 33rd ACM/IEEE International Conference on Automated Software Engineering. 2018.

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[8] Tufano, Michele, et al. "An empirical study on learning bug-fixing patches in the wild via neural machine translation." ACM Transactions on Software Engineering and Methodology (TOSEM) 28.4 (2019): 1-29.

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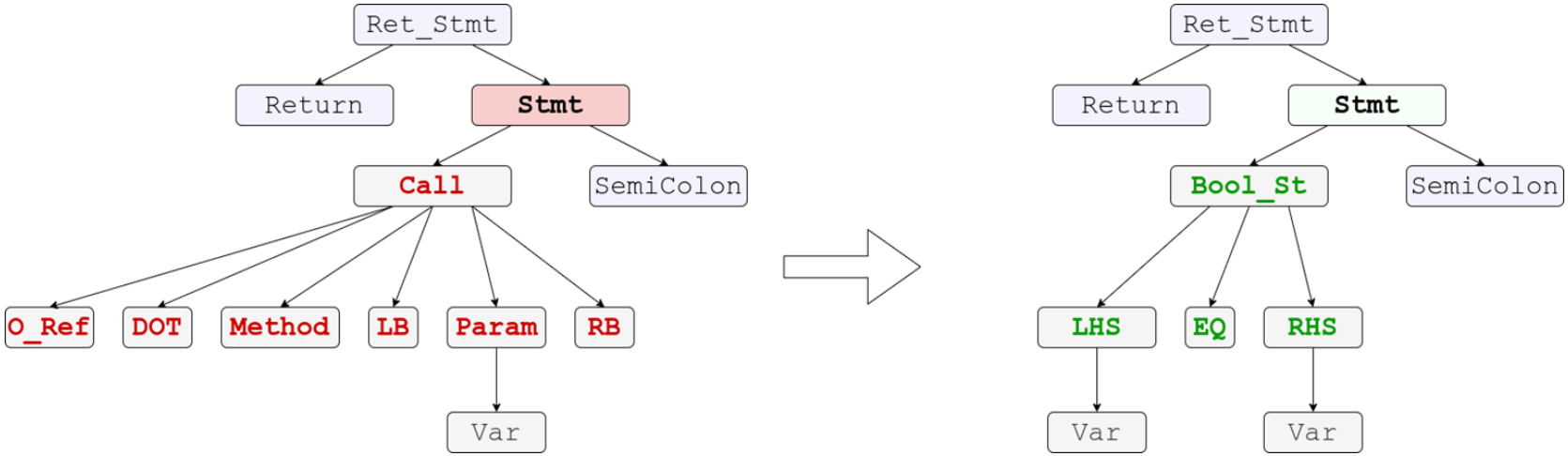
[22] Saha, Ripon K., et al. "Elixir: Effective object-oriented program repair." 2017 32nd IEEE/ACM International Conference on Automated Software Engineering (ASE). IEEE, 2017.

Thanks!

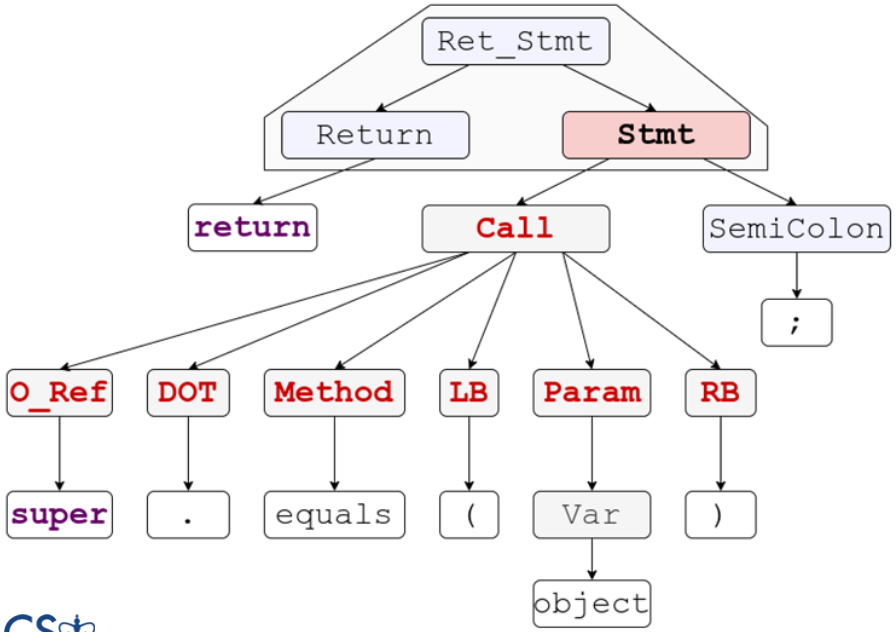
Backup Slides

CODIT Step 1 : Tree Translation



CODIT Step 1 : Tree Translation

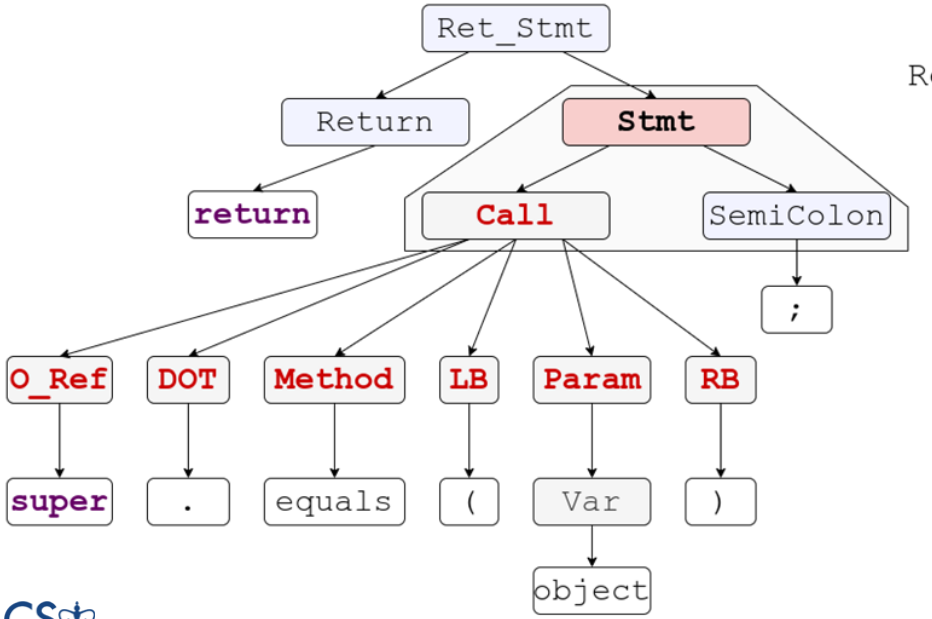
```
return super.equals(object);
```



Ret_Stmt ⟶ Return Stmt

CODIT Step 1 : Tree Translation

```
return super.equals(object);
```

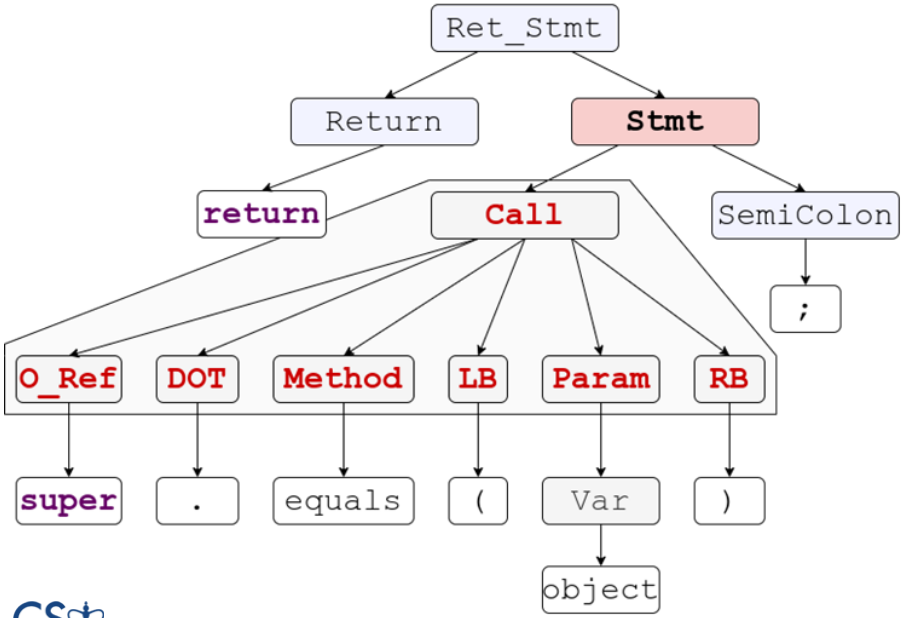


Ret_Stmt ⟶ Return Stmt

Stmt ⟶ Call SemiColon

CODIT Step 1 : Tree Translation

```
return super.equals(object);
```



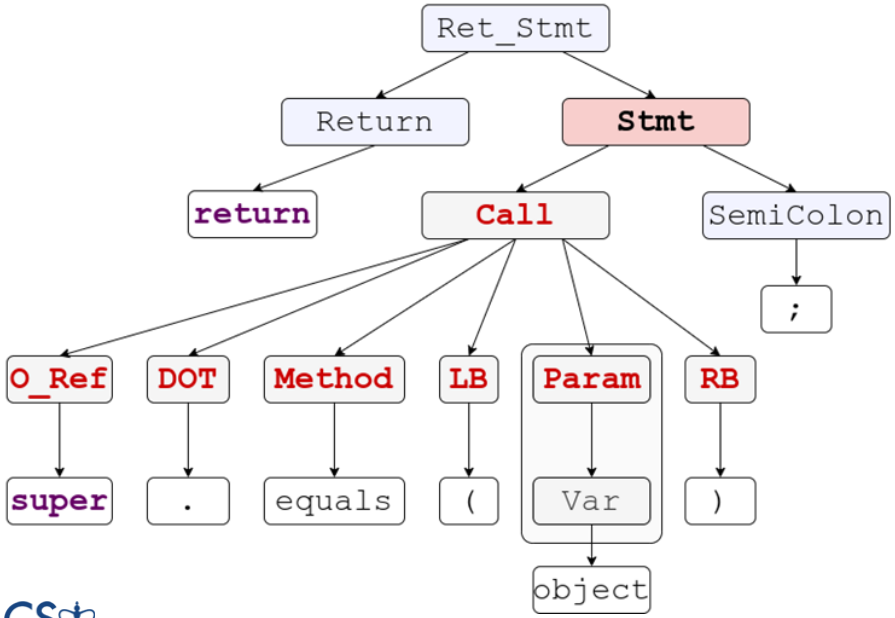
Ret_Stmt ⟶ Return Stmt

Stmt ⟶ Call SemiColon

Call ⟶ O_Ref DOT Method LB Param RB

CODIT Step 1 : Tree Translation

```
return super.equals(object);
```




```
Ret_Stmt ──→ Return Stmt
   Stmt  ──→ Call SemiColon
   Call  ──→ O_Ref DOT Method LB Param RB
  Param  ──→ Var
```

CODIT Step 1 : Tree Translation

Rules sequence of Syntax Tree before edit

```
Ret_Stmt ──→ Return Stmt
  Stmt   ──→ Call Semicolon
  Call   ──→ O_Ref DOT Method
                LB Param RB
 Param   ──→ Var
```

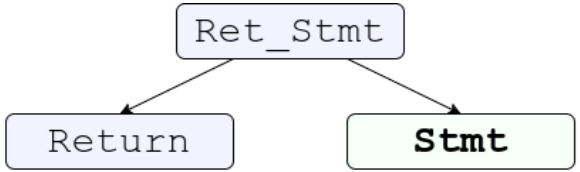
⇨

Rules sequence of Syntax Tree after edit

```
Ret_Stmt ──→ Return Stmt
  Stmt   ──→ Bool_St Semicolon
Bool_St  ──→ LHS EQ RHS
  LHS    ──→ VAR
  RHS    ──→ VAR
```

CODIT Step 1 : Tree Translation

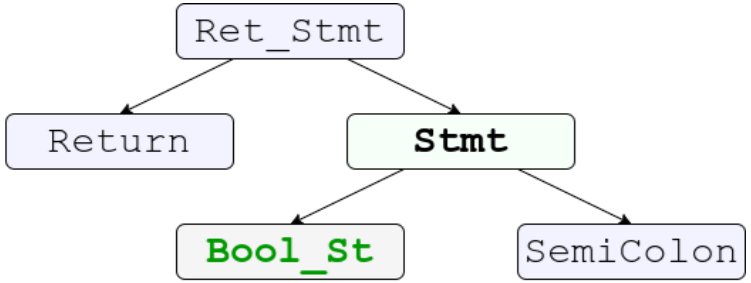
Ret_Stmt ⟶ Return Stmt



CODIT Step 1 : Tree Translation

Ret_Stmt ⟶ Return Stmt

Stmt ⟶ Bool_St Semicolon



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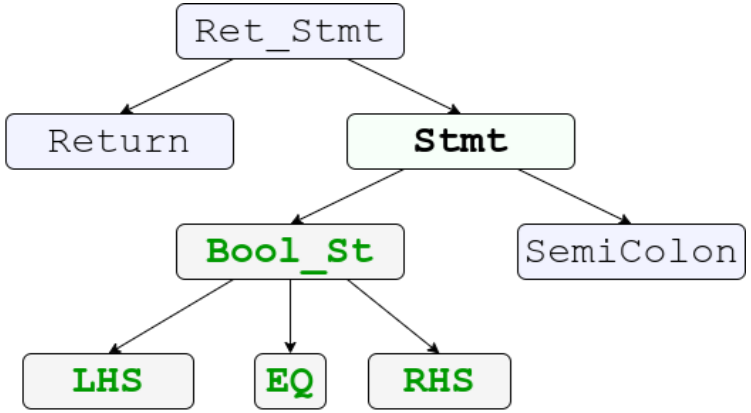

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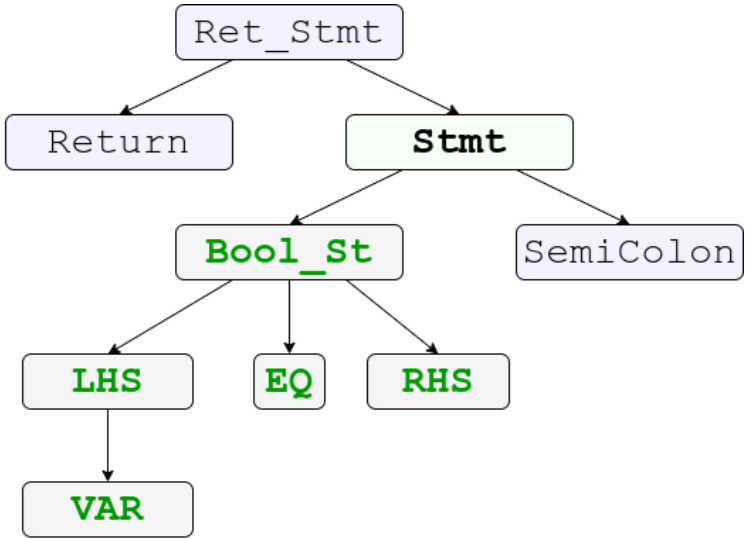

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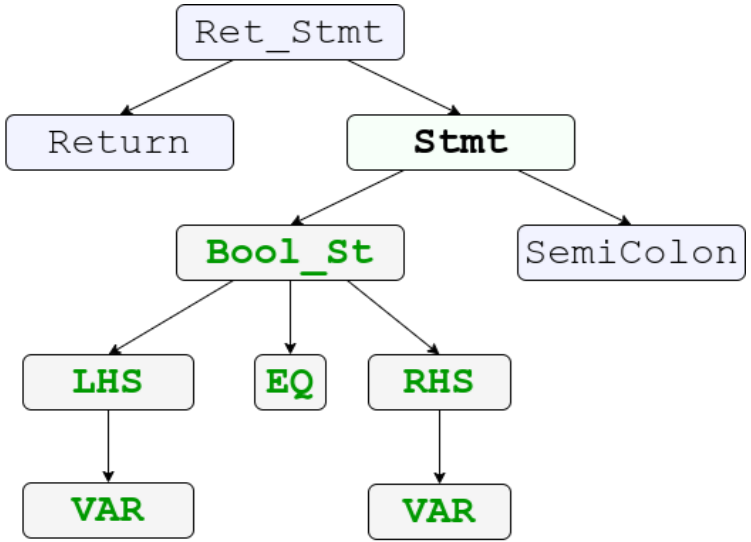

ReVeal: Program Understanding through Explicit Program Encoding

TSE - 2021

Findings

Graph-based models are better equipped to understand semantic relationships between code components

Contribution

Designed Code Understanding Framework using Graph-Based Models.

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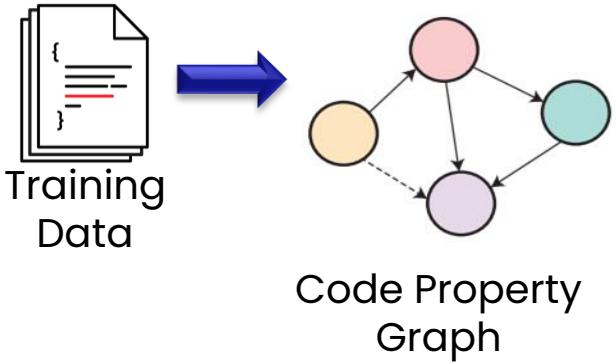
ReVeal : Explicit Encoding for Program Understanding

Training Data

ReVeal : Explicit Encoding for Program Understanding



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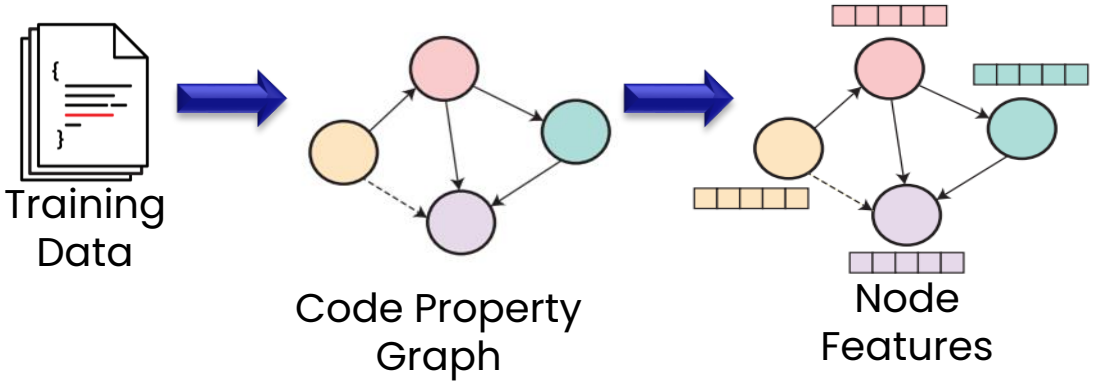

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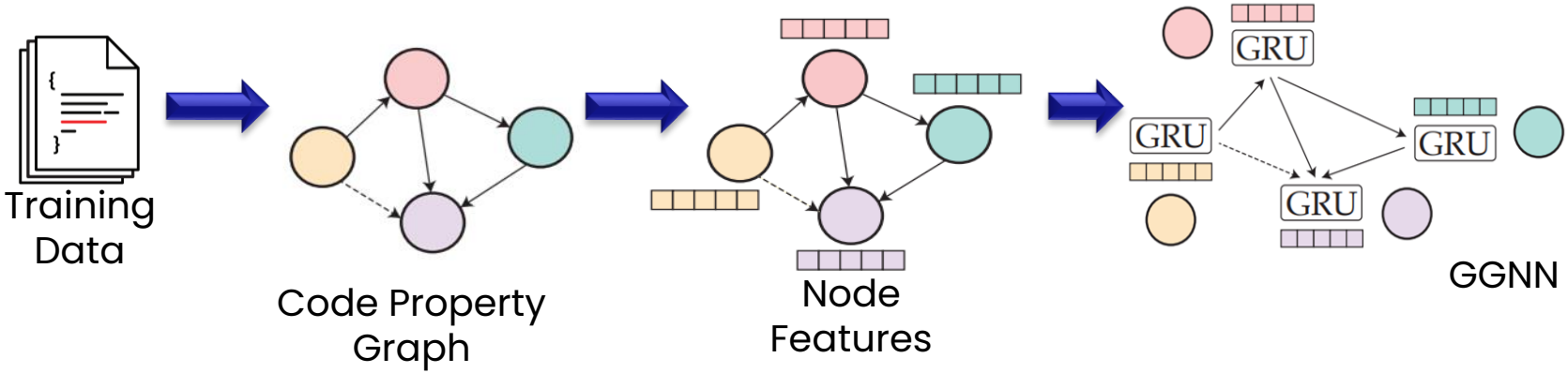

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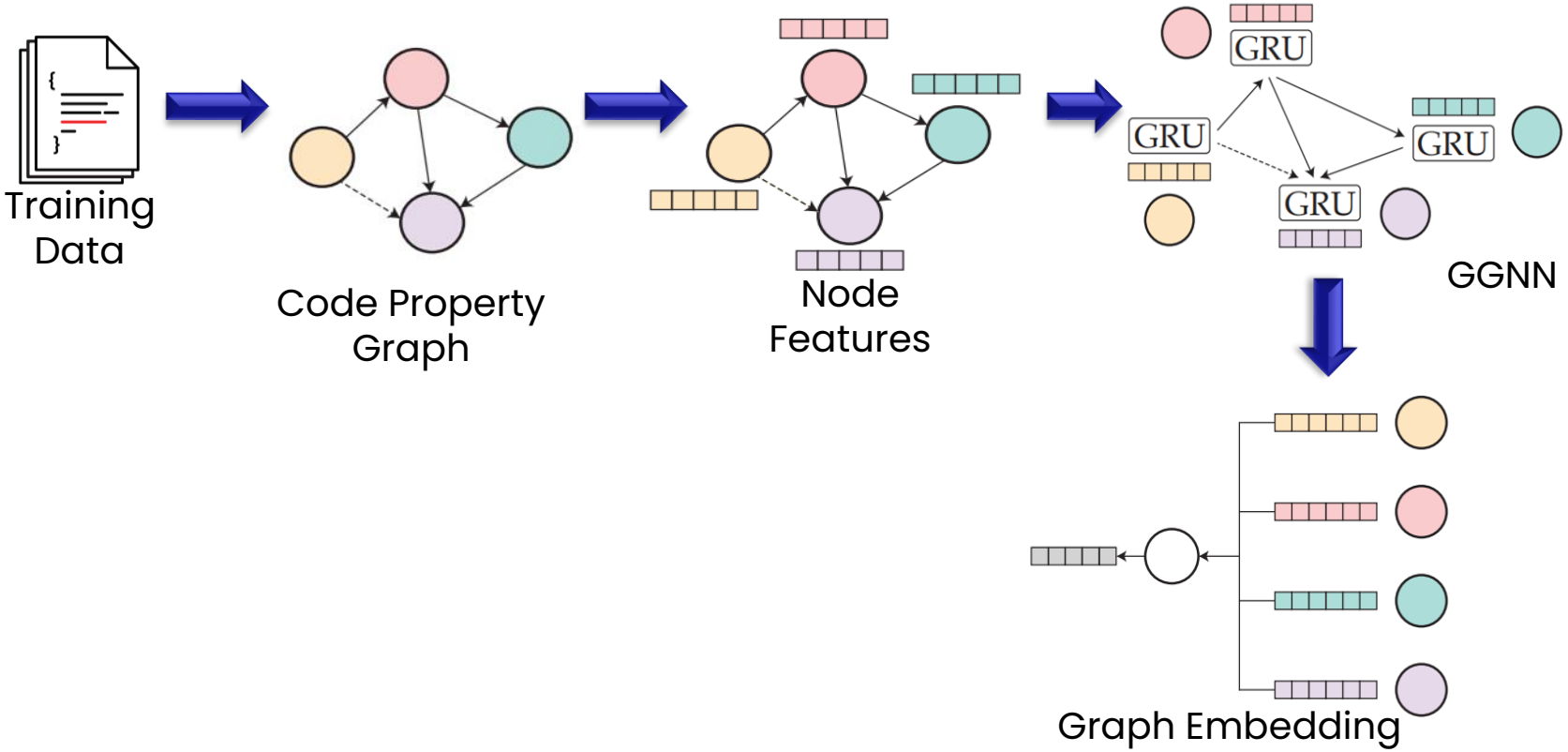

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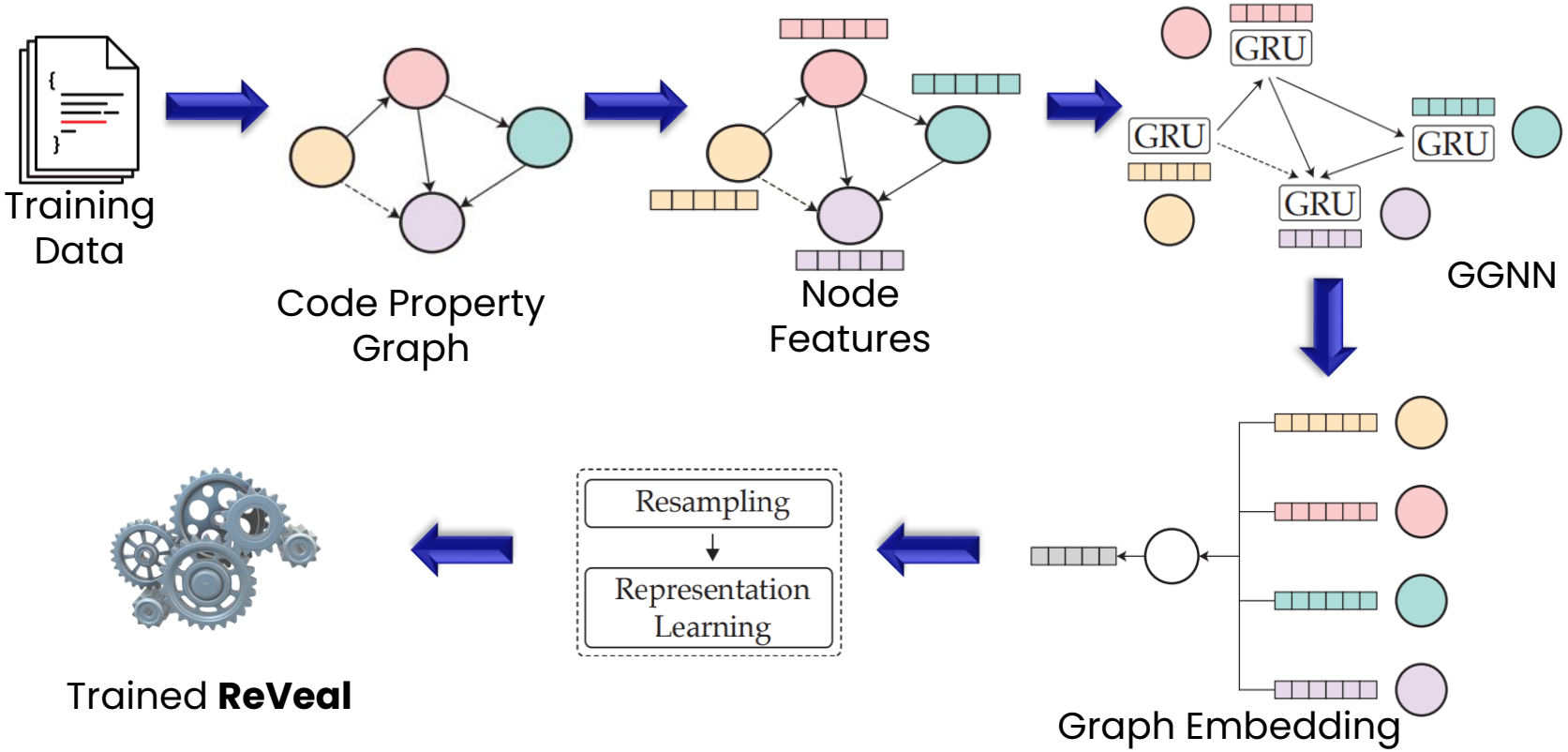

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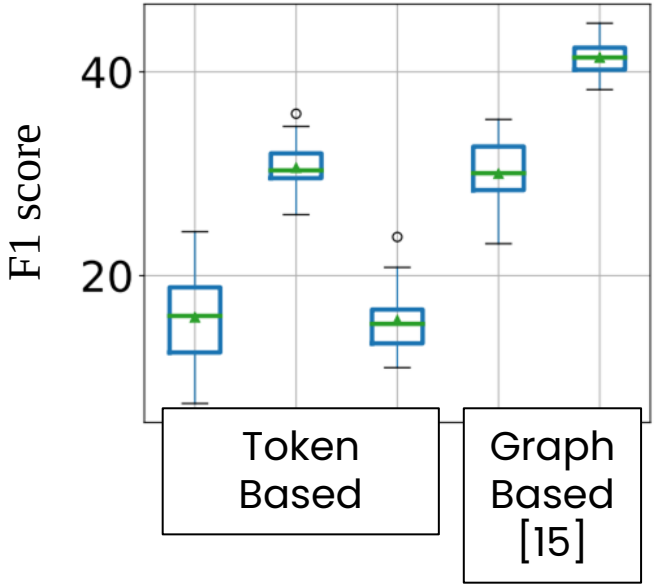
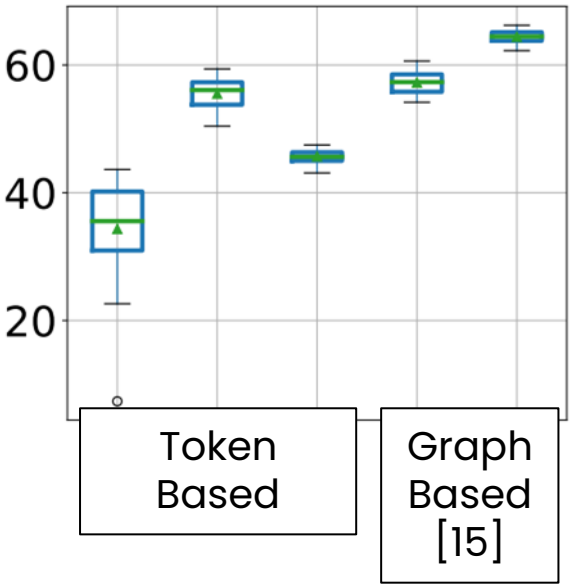


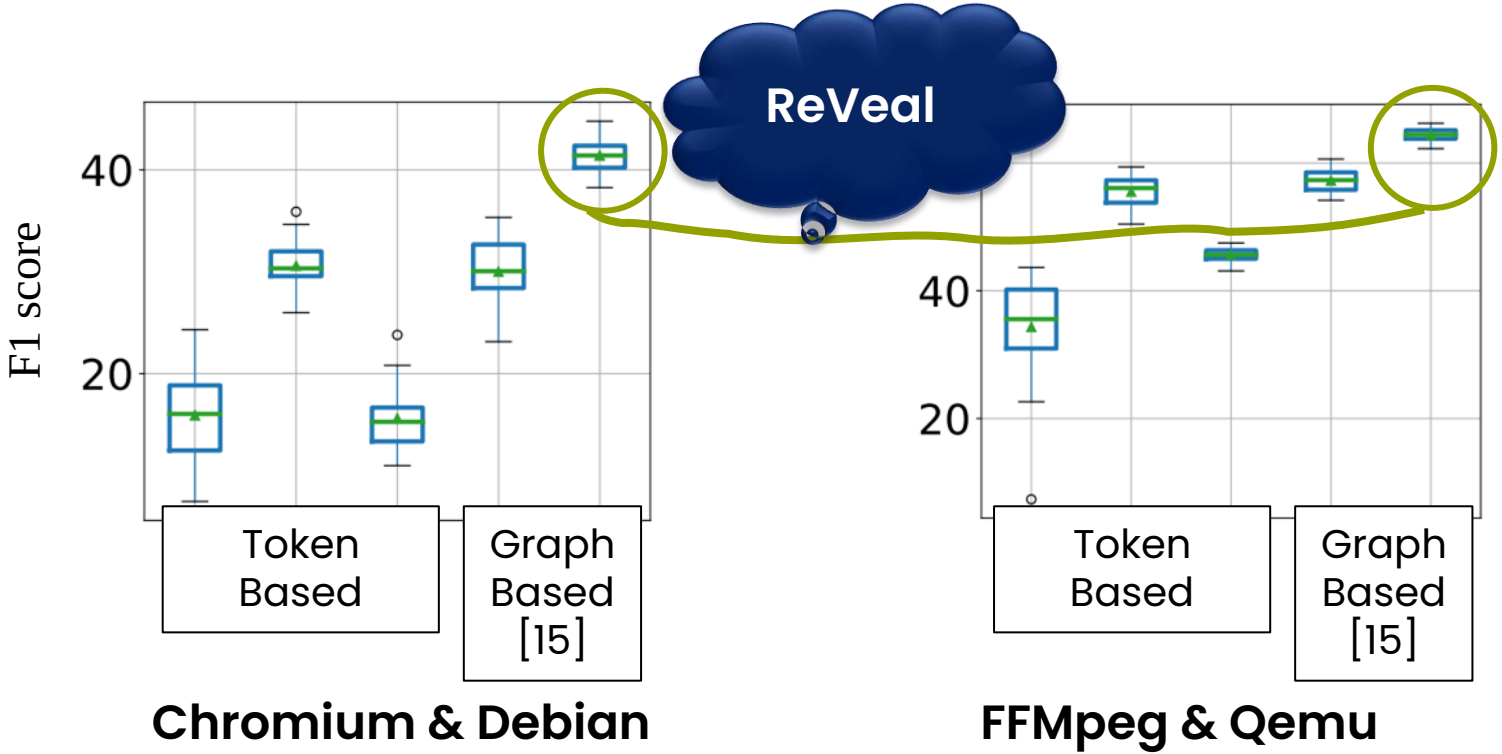
Chromium & Debian



FFMpeg & Qemu

CS@CU

ReVeal : Explicit Encoding for Program Understanding



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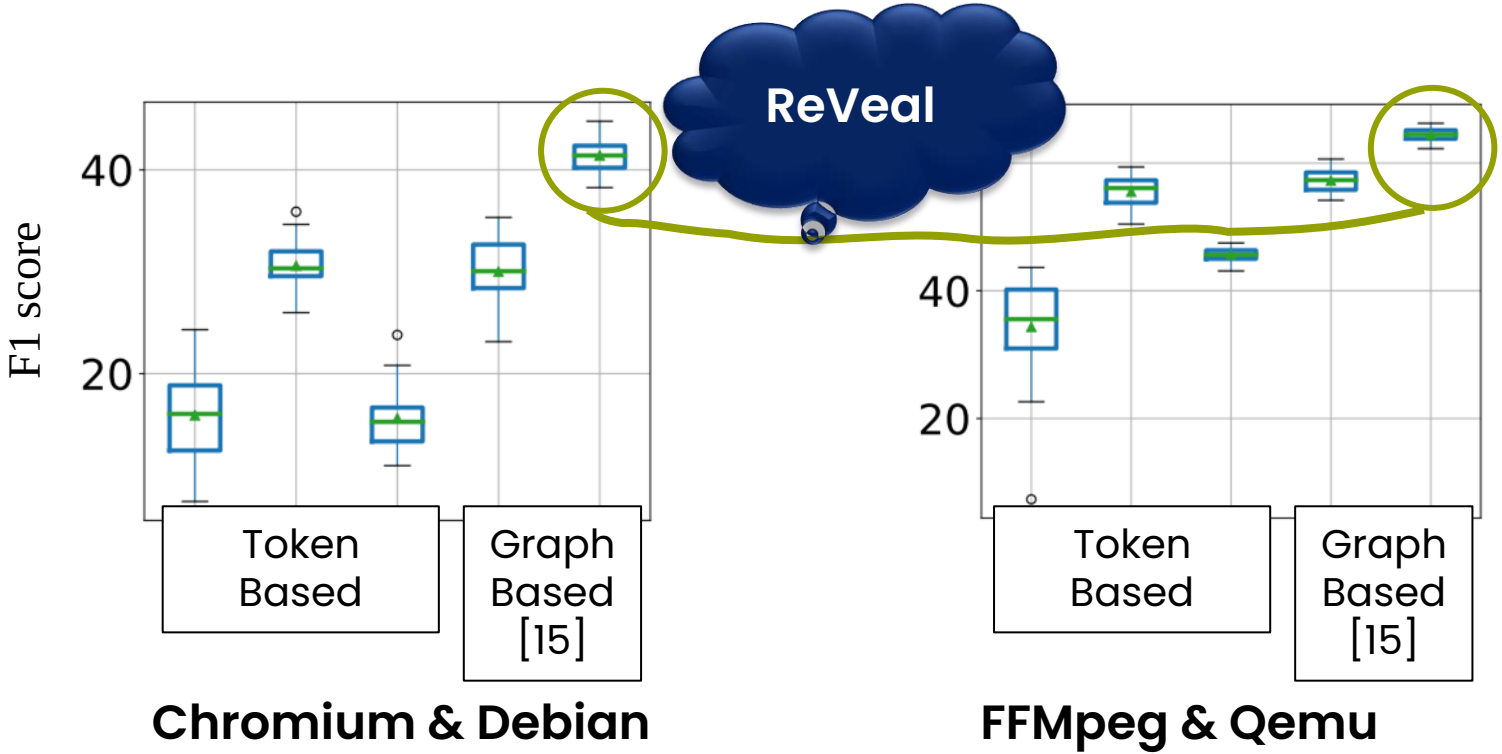
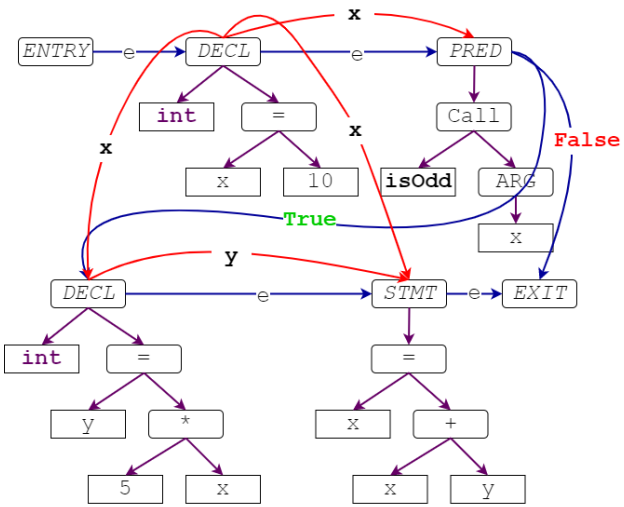
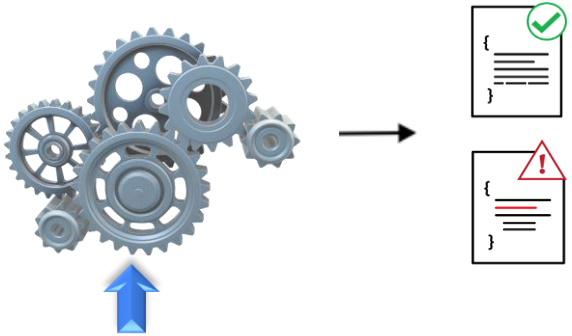


[15] Devign Zhou et. al. 2019

Explicit Encoding PL knowledge into model



Code Property Graph



Data Flow

Control Flow

AST

PLBART Results

- Code Summarization

Methods	Ruby	Javascript	Go	Python	Java	PHP	Overall
Seq2Seq	9.64	10.21	13.98	15.93	15.09	21.08	14.32
Transformer	11.18	11.59	16.38	15.81	16.26	22.12	15.56
RoBERTa	11.17	11.90	17.72	18.14	16.47	24.02	16.57
CodeBERT	12.16	14.90	18.07	19.06	17.65	**25.16**	17.83
PLBART	**14.11**	**15.56**	**18.91**	**19.30**	**18.45**	23.58	**18.32**

PLBART Results

- Code Generation from Natural Language

Methods	EM	BLEU	CodeBLEU
Seq2Seq	3.05	21.31	26.39
Guo et al. (2019)	10.05	24.40	29.46
Iyer et al. (2019)	12.20	26.60	-
GPT-2	17.35	25.37	29.69
CodeGPT-2	18.25	28.69	32.71
CodeGPT-adapted	**20.10**	32.79	35.98
PLBART	18.75	**36.69**	**38.52**
PLBART$_{10K}$	17.25	31.40	33.32
PLBART$_{20K}$	18.45	34.00	35.75
PLBART$_{50K}$	17.70	35.02	37.11

PLBART Results

- Code Translation

Methods	Java to C#			C# to Java		
	BLEU	EM	CodeBLEU	BLEU	EM	CodeBLEU
Naive Copy	18.54	0	34.20	18.69	0	43.04
PBSMT	43.53	12.50	42.71	40.06	16.10	43.48
Transformer	55.84	33.00	63.74	50.47	37.90	61.59
RoBERTa (code)	77.46	56.10	83.07	71.99	57.90	80.18
CodeBERT	79.92	59.00	85.10	72.14	58.80	79.41
GraphCodeBERT	80.58	59.40	-	72.64	58.80	-
PLBART	**83.02**	**64.60**	**87.92**	**78.35**	**65.00**	**85.27**

PLBART Results

- Code Classification - % Accuracy for Vulnerability, F1 score for Clone Detection.

Tasks	Vulnerability Detection	Clone Detection
Transformer	61.64	-
CodeBERT	62.08	96.5
GraphCodeBERT	-	97.1
PLBART	**63.18**	**97.2**

Code Translation Example

Input Code : C#

```
1 public int GetCells(){
2     int size = 0;
3     foreach (char c in cells.Keys){
4         Cell e = At(c);
5         if (e.cmd >= 0 || e.@ref >= 0){
6             size++;
7         }
8     }
9     return size;
10 }
```

Generated Code : Java

```
1 public int getCells() {
2     Iterator<Character> i =
3       cells.keySet().iterator();
4     int size = 0;
5     for (; i.hasNext();) {
6         Character c = i.next();
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-       pictures = new ArrayList<>();

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Transformers can learn syntax

Model Name	# of params (M)	Multi-Modal	Accuracy (%)	
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Transformer-base	139.22	✓	11.18	6.61
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CODIT	105.43	✗	6.53	4.79

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Pretrained models improves Code editing

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Impact of Different Information Modality.

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|——~~Both Context and Guidance~~	26.67	19.79
SequqnceR [Chen *et al.*, TSE 19]	13.03	4.53
SequenceR + Guidance	17.90	4.60

Impact of Different Information Modality.

Impact of Guidance

```
// Guidance: fixed some bugs in type checking
// improved performance by caching types of expressions
private TypeCheckInfo getType(SadlUnionType expression){
    ...
    return new TypeCheckInfo(
-       declarationConceptName, declarationConceptName
        /* MODIT generated patch with guidance */
+       declarationConceptName, declarationConceptName,
+       this, expression
        /* MODIT generated patch without guidance */
+       this.declarationConceptName,
+       this.declarationConceptName
    );
}
```

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// improved performance by caching types of expressions
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+       this.declarationConceptName,
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    );
}
```

Impact of Different Information Modality.

Impact of Context

```
// Guidance: Fix bug of sending wrong message
public void setPredecessor (model.Message m) {
    this.predecessor = Integer.valueOf(m.Content);
    model.Message sent = new model.Message();
    sent.To = m.Origin;
-   sendMessage(m);
    /* MODIT generates with the context. */
+   sendMessage(sent);
    /* MODIT generates without context as input. */
+   sendMessage(m.toString());
}
```

Impact of Different Information Modality.

Impact of Context

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// Guidance: Fix bug of sending wrong message
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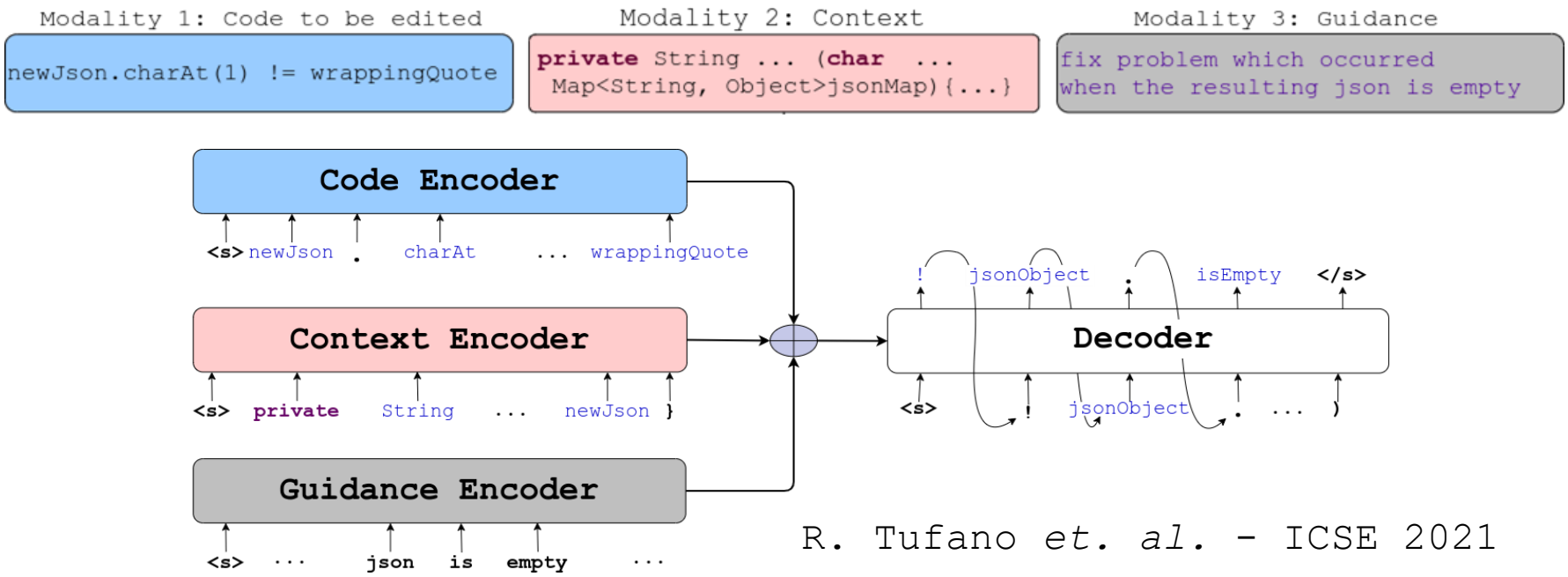
Best way to encode input Modalities.



R. Tufano *et. al.* - ICSE 2021

Best way to encode input Modalities.

# of Modalities	# of Encoders	Accuracy (%)	
		$B2F_s$	$B2F_m$

Best way to encode input Modalities.

# of Modalities	# of Encoders	Accuracy (%)	
		$B2F_s$	$B2F_m$
3 (e_p, $\mathcal{G}$, C)	3	20.63	11.69
	1	**26.05**	**17.13**

Best way to encode input Modalities.

# of Modalities	# of Encoders	Accuracy (%)	
		$B2F_s$	$B2F_m$
2 $(e_p, \mathcal{G})$	2	23.12	15.49
	1	**23.81**	**17.46**

Best way to encode input Modalities.

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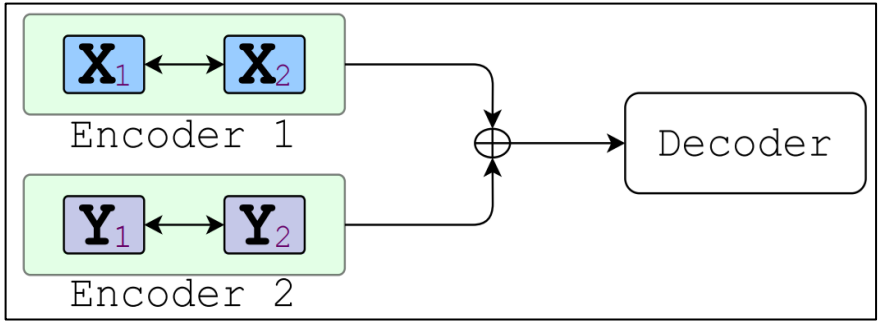
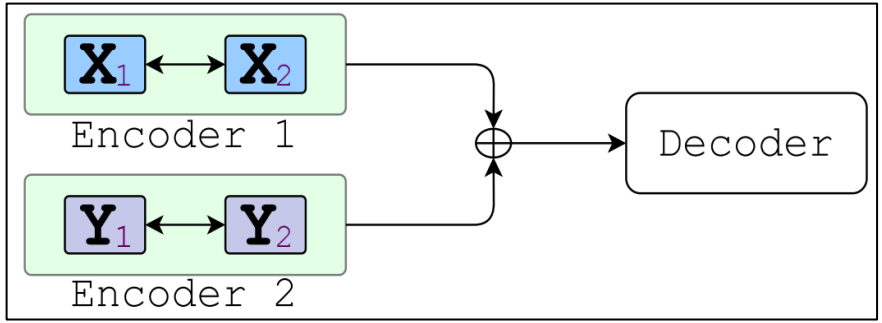
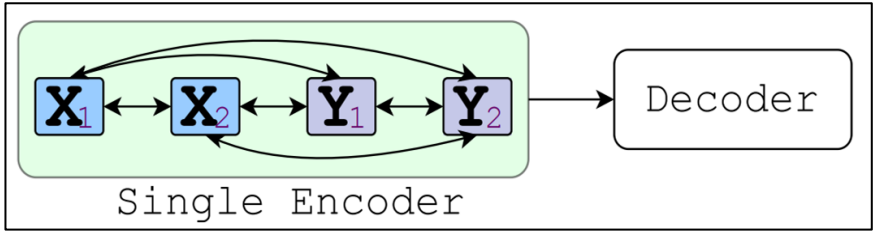


Best way to encode input Modalities.





NatGen: Code Generation By Pretrained Models

Model	Syntax Match (%)	Dataflow Match (%)	CodeBLEU (%)	Direct Copy (%)	Avg. Edit Distance
CodeT5[18]	13.83	23.67	10.87	0	65
PLBART	73.17	75.95	74.56	7.05	3
NatGen	98.16	96.85	96.82	0.01	10

[18] Wang et al. 2021

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1. Input

```
protected SDV iam(SDV in,...){
    if(i < i){
        return new IAM(...);
    }
    return new IAM(...);
}
```

[18] Wang et al. 2021

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    }
    return new IAM(...);
}
```

2. PLBART output

```
SDV iam(SDV in, ...){
    if(i < i){
        return new IAM(...);
    }
    return new IAM(...);
}
```

[18] Wang et al. 2021

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    }
    return new IAM(...);
}
```

3. NatGen output

```
protected SDV iam(SDV in,...){
    return new IAM(...);
}
```

[18] Wang et al. 2021

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    }
    return new IAM(...);
}
```

2. PLBART output

```
SDV iam(SDV in, ...){
    if(i < i){
        return new IAM(...);
    }
    return new IAM(...);
}
```

3. NatGen output

```
protected SDV iam(SDV in,...){
    return new IAM(...);
}
```

4. CodeT5 output

```
if (in) {
    return
}  }
```

[18] Wang et al. 2021

NatGen Results

- NL to Code Generation

Approach		EM	SM	DM	CB
Seq2Seq		3.05	-	-	26.39
Guo et al. [30]		10.05	-	-	29.46
Iyer et al. [37]		12.20	-	-	-
GPT-2		17.30	-	-	29.69
CodeGPT		20.10	-	-	35.98
PLBART		18.75	-	-	38.52
CodeT5-base (reported)		**22.30**	-	-	43.20
CodeT5*	$\mathcal{M}_{last}$	21.85	44.34	44.52	41.75
	$\mathcal{M}_{best}$	21.55	41.08	43.71	38.30
NatGen	$\mathcal{M}_{last}$	22.25	**45.59**	**46.87**	**43.73**
	$\mathcal{M}_{best}$	**22.30**	44.38	45.64	42.44

* Our reproduced result using CodeT5's publicly available pre-trained model.

NatGen Results

- Code Translations

Approach	Java → C#				C# → Java			
	EM	SM	DM	CB	EM	SM	DM	CB
PBSTM	12.5	-	-	42.7	16.1	-	-	43.5
CodeBERT	59.0	-	-	85.1	58.8	-	-	79.4
SPT-Code	64.1	-	-	-	60.2	-	-	-
PLBART	64.6	-	-	87.9	65.0	-	-	**85.3**
CodeT5 (reported)	65.9	-	-	-	66.9	-	-	-
CodeT5*	65.9	90.4	91.9	87.8	66.0	90.4	88.9	84.4
NatGen	**66.2**	**91.0**	**92.0**	**88.1**	**67.3**	**91.0**	**89.8**	85.2

* Our reproduced result using CodeT5's publicly available pre-trained model.

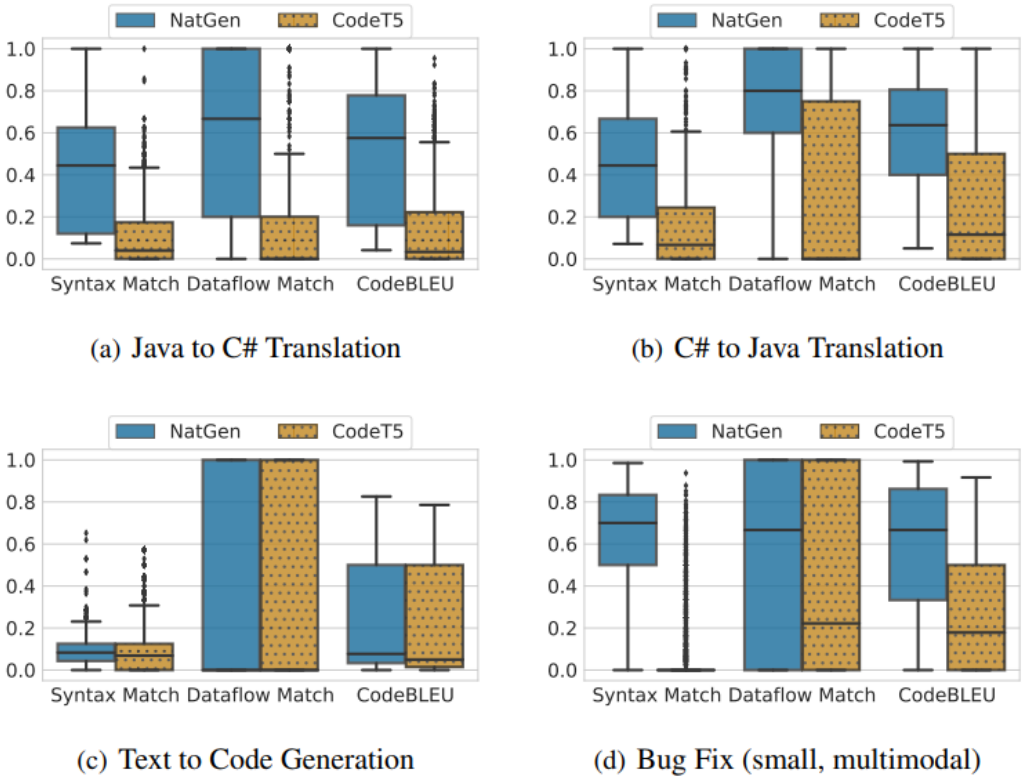
NatGen Results

- Code Summarization

Approach	Go	Java	JS	Python	Php	Ruby	Overall
PLBART	18.91	18.45	15.56	19.30	23.58	14.11	18.32
CodeT5	**19.56**	20.31	**16.16**	20.01	**26.03**	15.24	19.55
NatGen	19.43	**20.38**	16.00	**20.09**	26.00	**15.38**	19.55

NatGen Results

- Zero Shot Learning



(a) Java to C# Translation

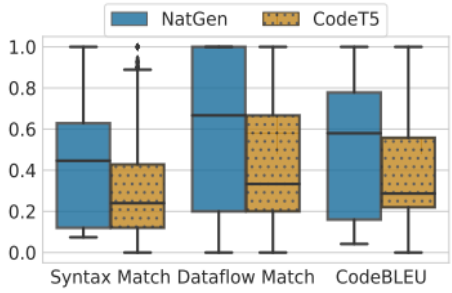
(b) C# to Java Translation

(c) Text to Code Generation

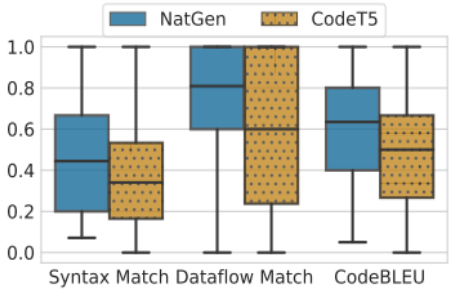
(d) Bug Fix (small, multimodal)

NatGen Results

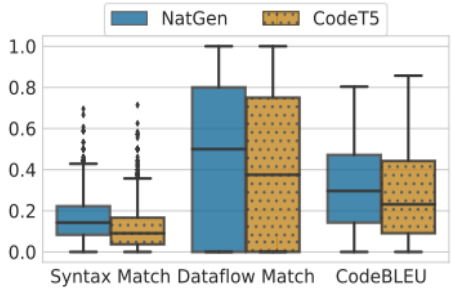
- Few Shot Learning



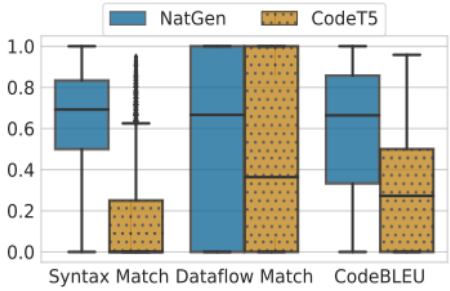
(a) Java to C# Translation



(b) C# to Java Translation



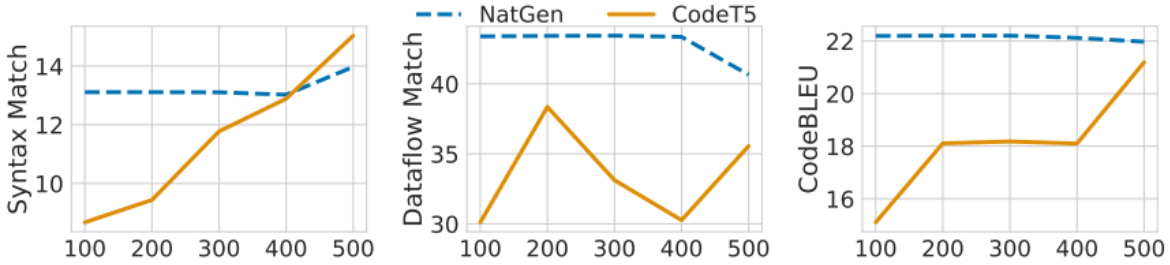
(c) Text to Code Generation



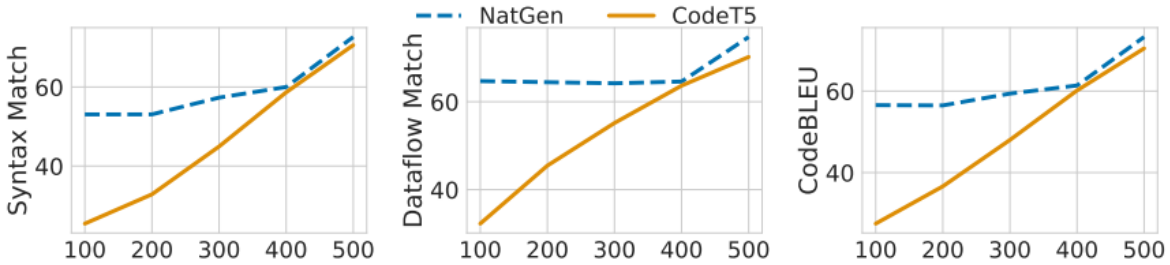
(d) Bug Fix (small, multimodal).

NatGen Results

- Few Shot - Ablation



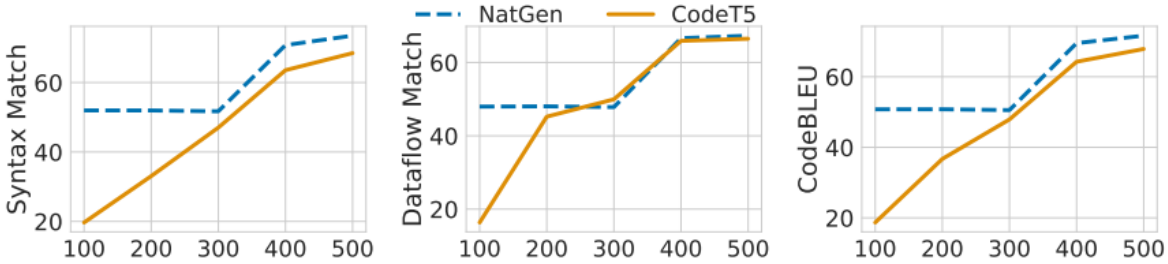
(a) Text to Code Generation.



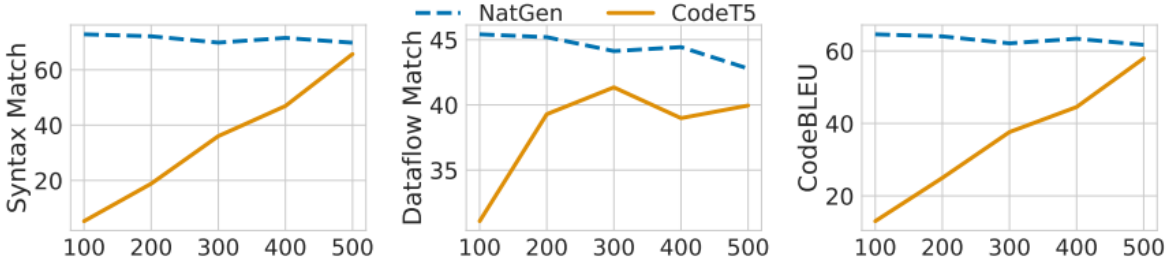
(b) C# to Java Translation.

NatGen Results

- Few Shot - Ablation



(c) Java to C# Translation.



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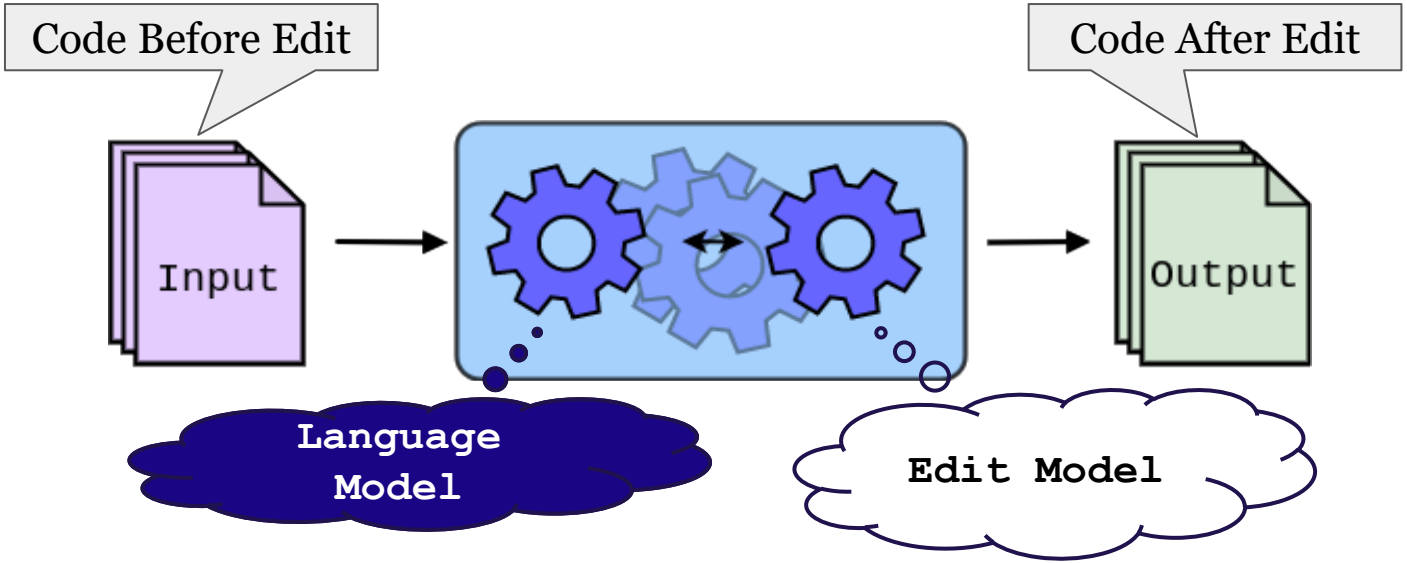
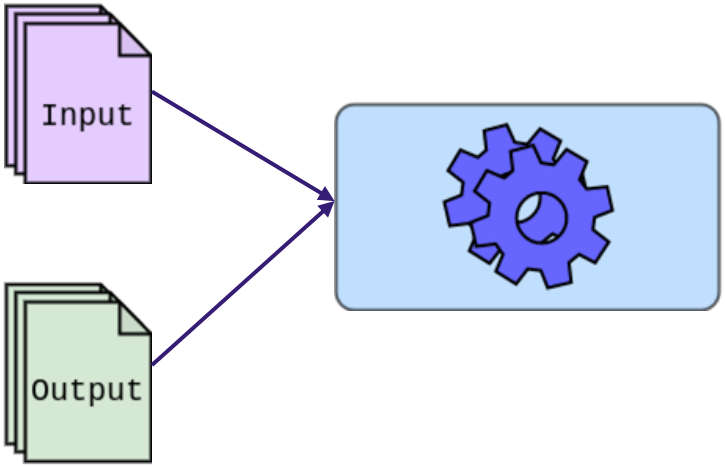
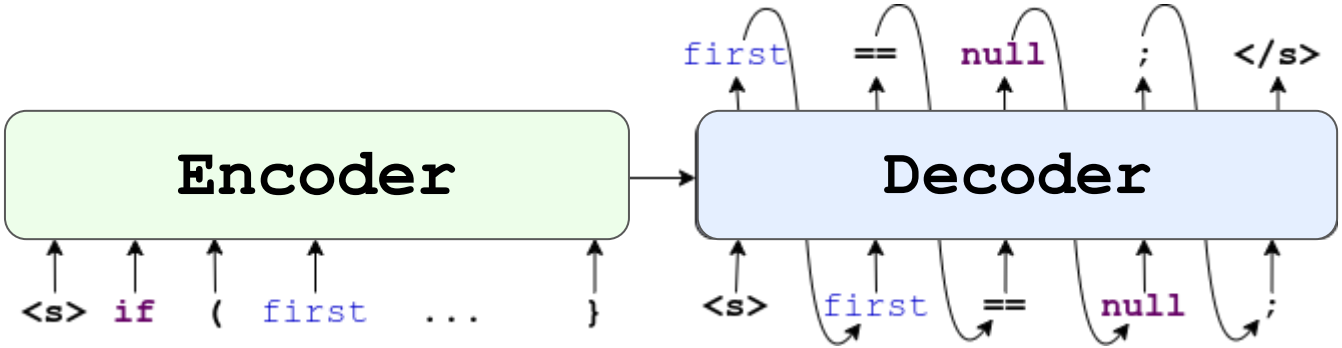

Code Before Edit
Code After Edit
Input
Output
Language Model
Edit Model



Pretraining - Embed the knowledge of **input and output** into the model.

PLBART - Pretraining both encoder and decoder.



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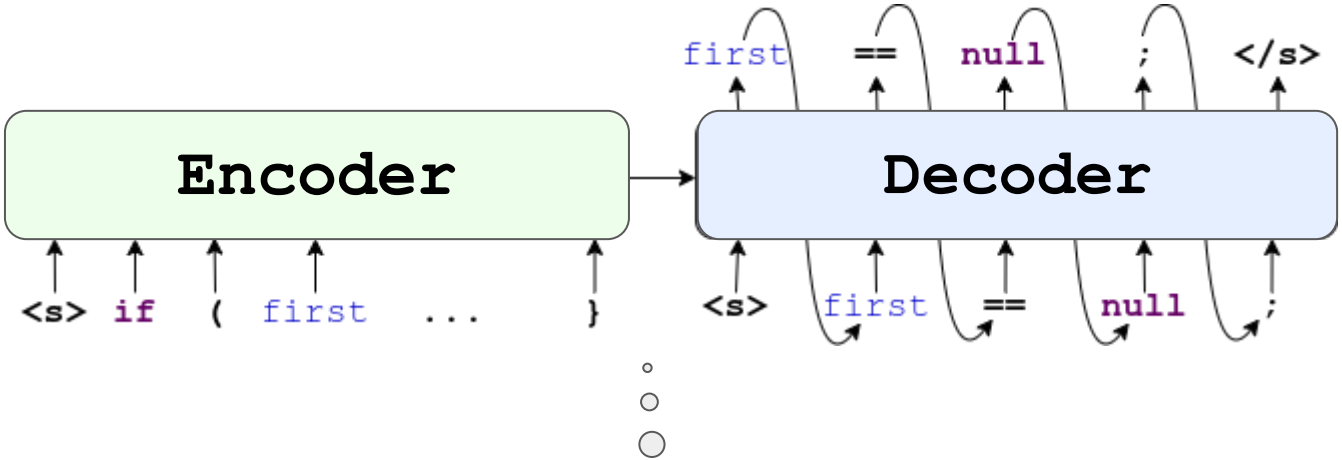


What Type of Model should we use?

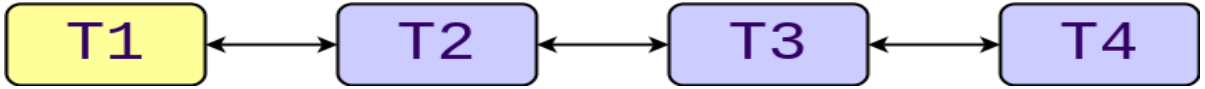
Recurrent Model Vs. Transformer Model

Recurrent Model Vs. Transformer Model

1. Recurrent Model

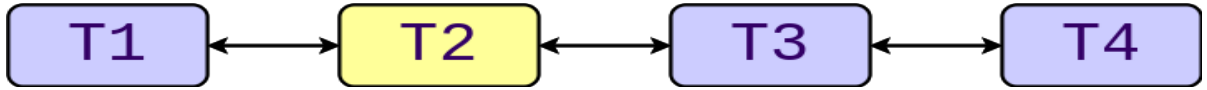
Recurrent Model Vs. Transformer Model

1. Recurrent Model



Recurrent Model Vs. Transformer Model

1. Recurrent Model



Recurrent Model Vs. Transformer Model

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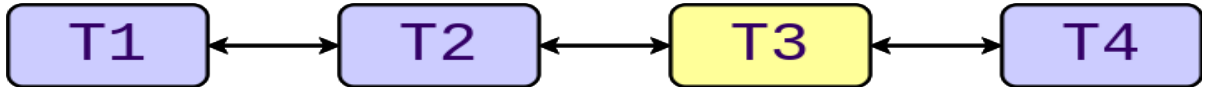

Recurrent Model Vs. Transformer Model

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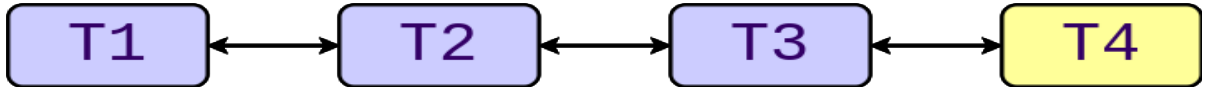
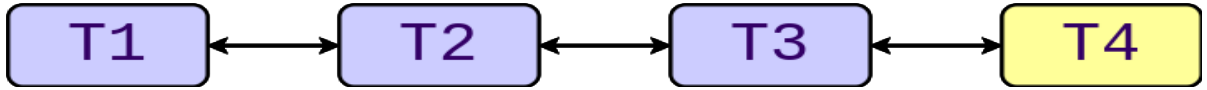


Recurrent Model Vs. Transformer Model

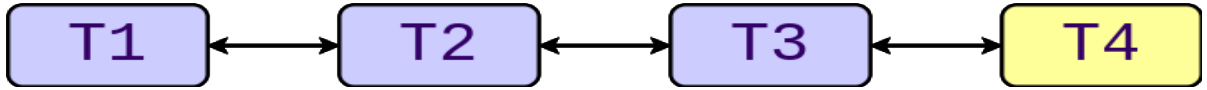
1. Recurrent Model



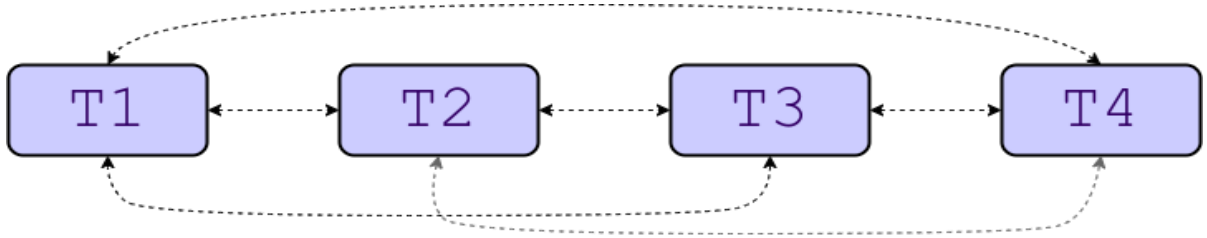
2. Transformer Model

Recurrent Model Vs. Transformer Model

1. Recurrent Model



2. Transformer Model



Recurrent Model Vs. Transformer Model

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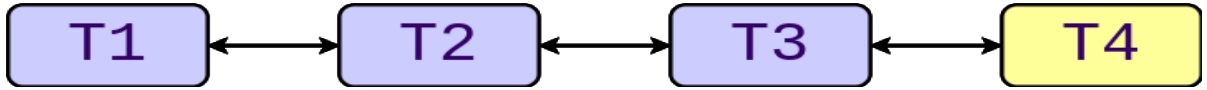
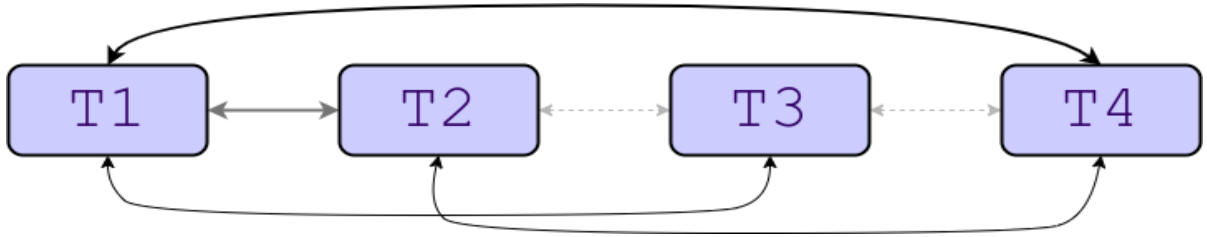


2. Transformer Model



Recurrent Model Vs. Transformer Model

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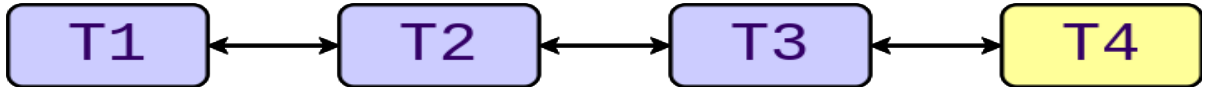

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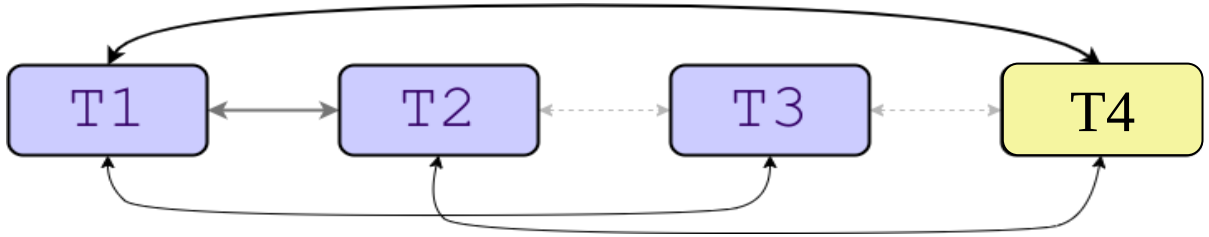

Recurrent Model Vs. Transformer Model

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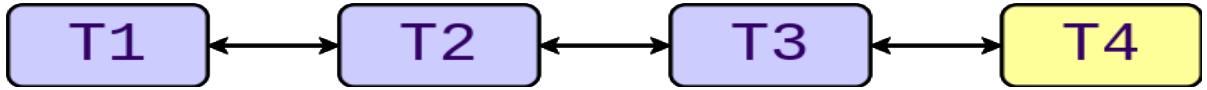
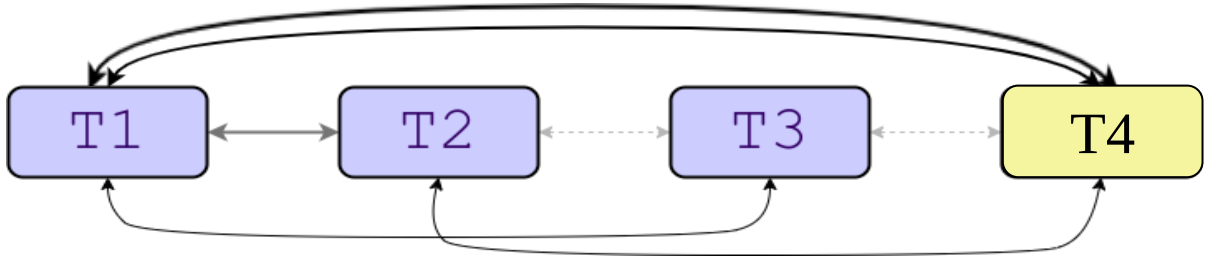
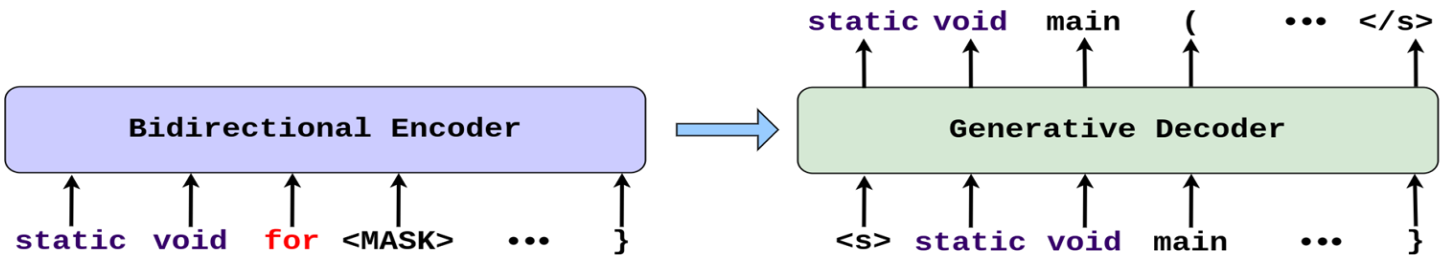
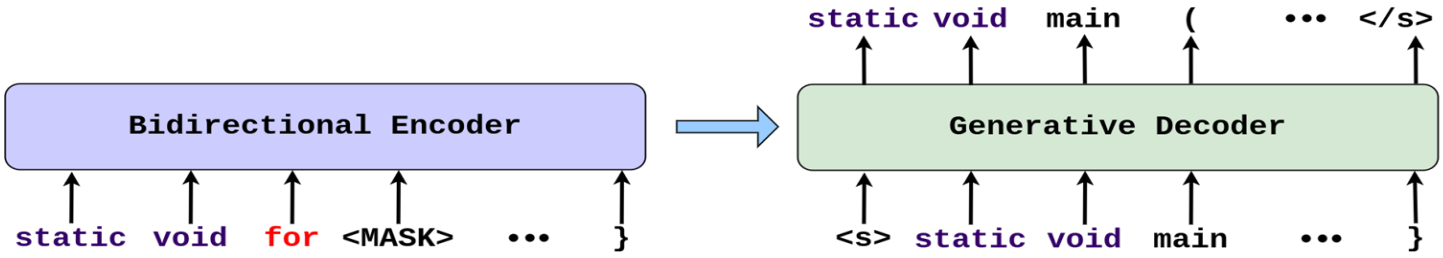


2. Transformer Model




static void main (••• </s>
Bidirectional Encoder
Generative Decoder
static void for <MASK> ••• }
<s> static void main ••• }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Bidirectional Encoder
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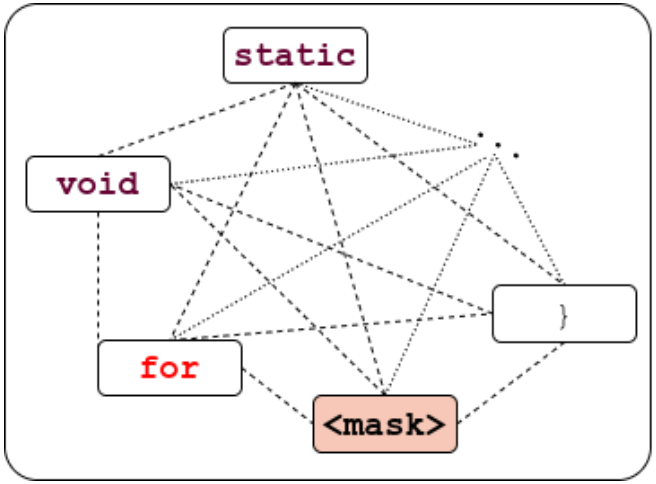
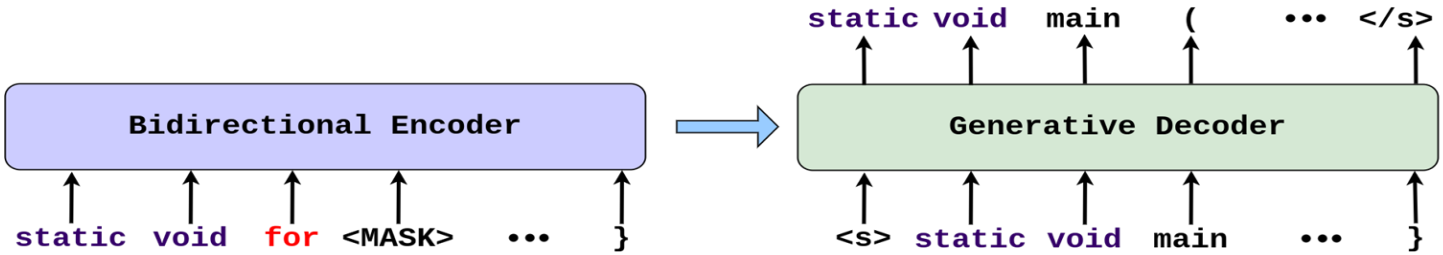

static
void
}
for
<mask>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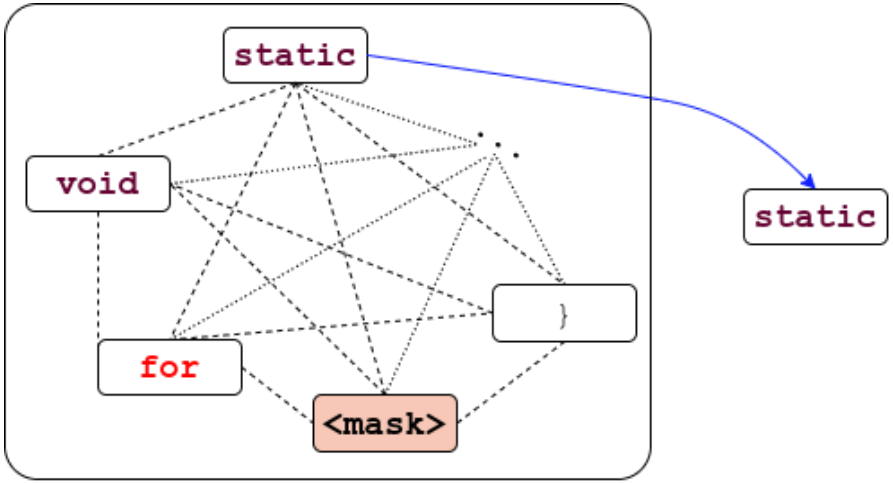
static
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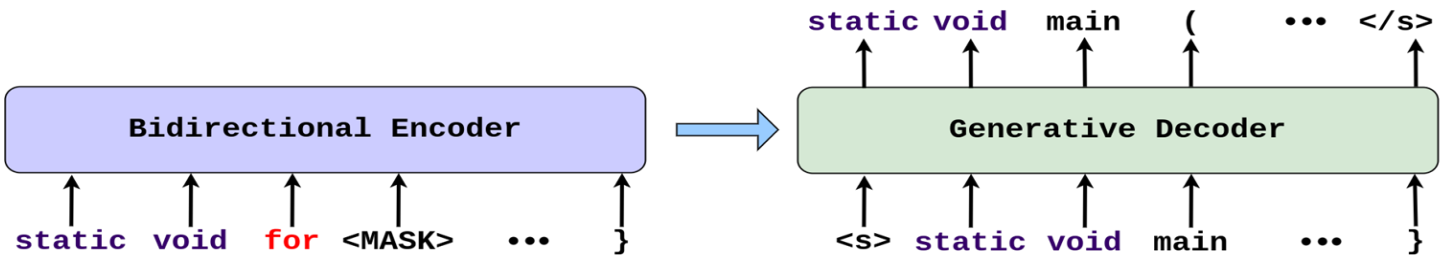
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static void for <MASK> ••• }
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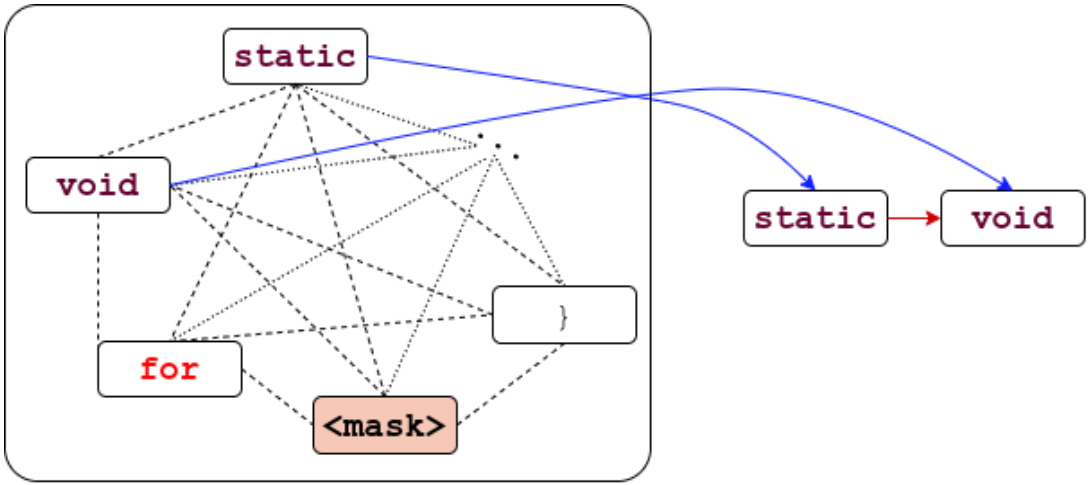
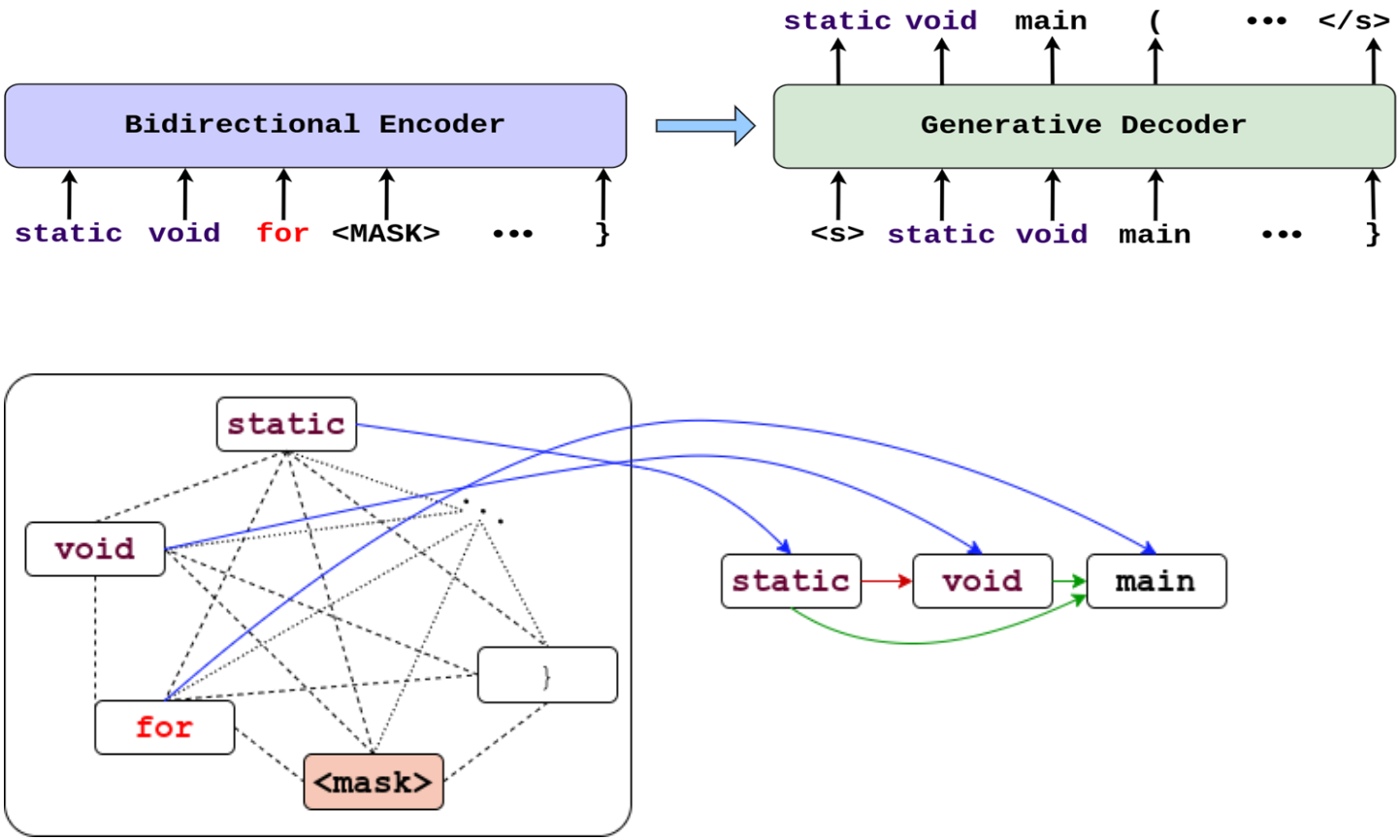
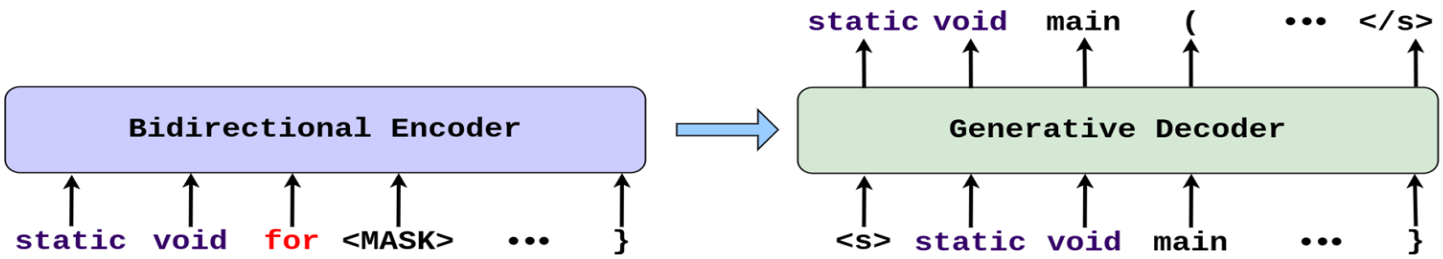

static
void
}
for
<mask>
static
void


static void main (••• </s>
Bidirectional Encoder
Generative Decoder
static void for <MASK> ••• }
<s> static void main ••• }
static
void
for
<mask>
}
static
void
main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Bidirectional Encoder
Generative Decoder
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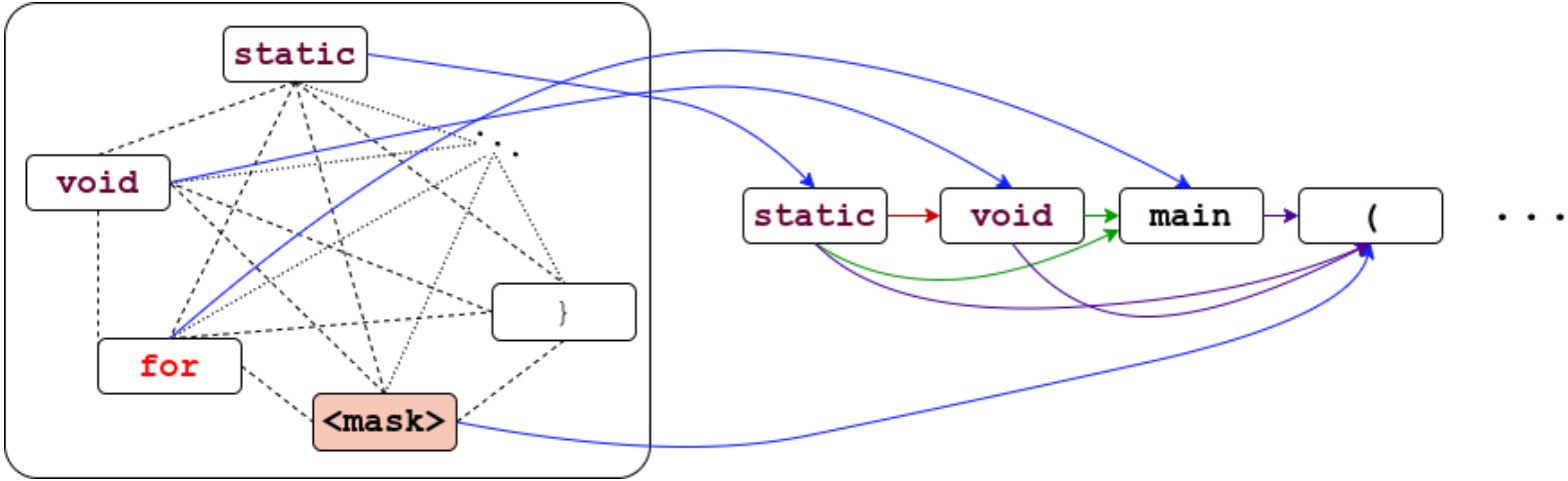
static
void
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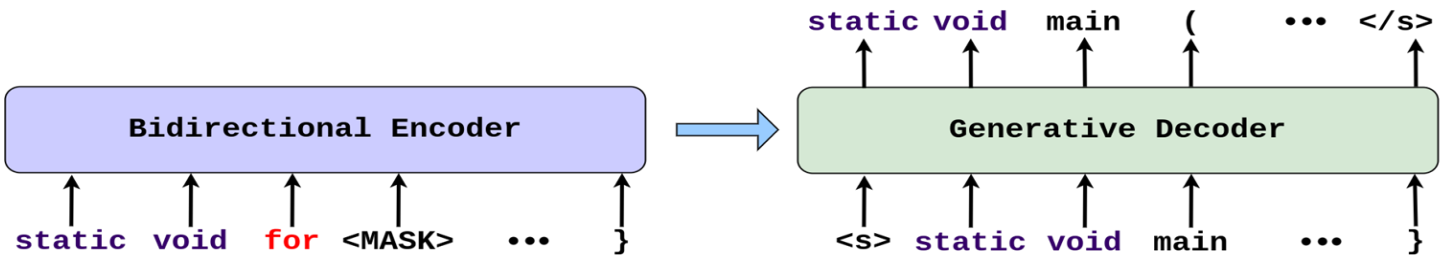
(
. . .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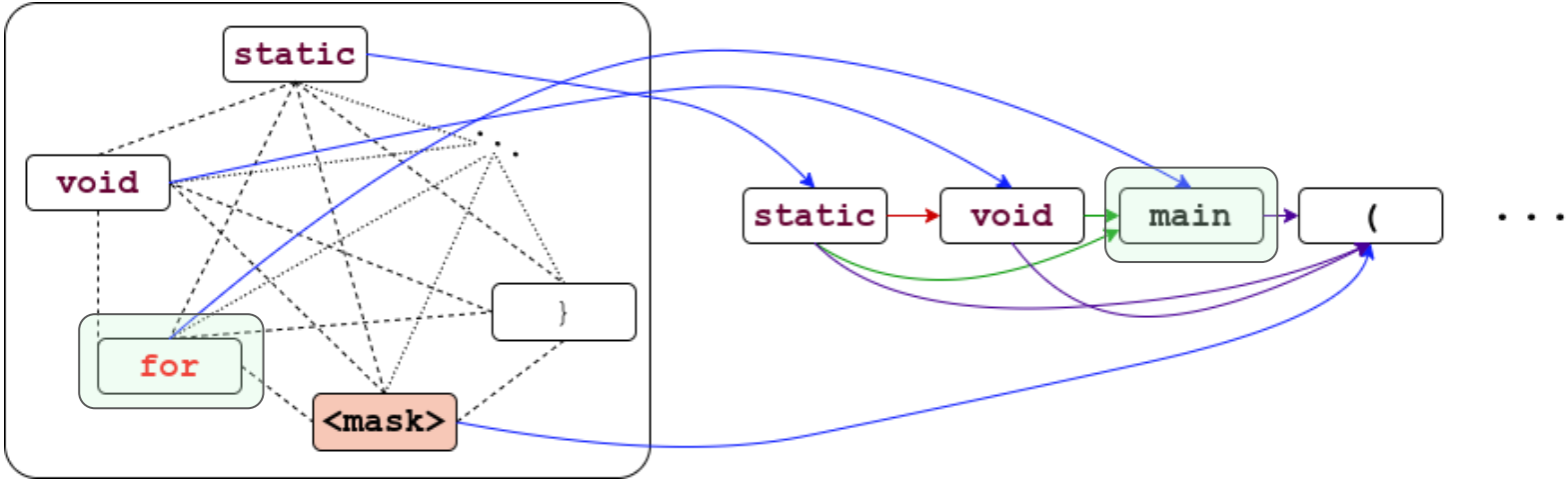
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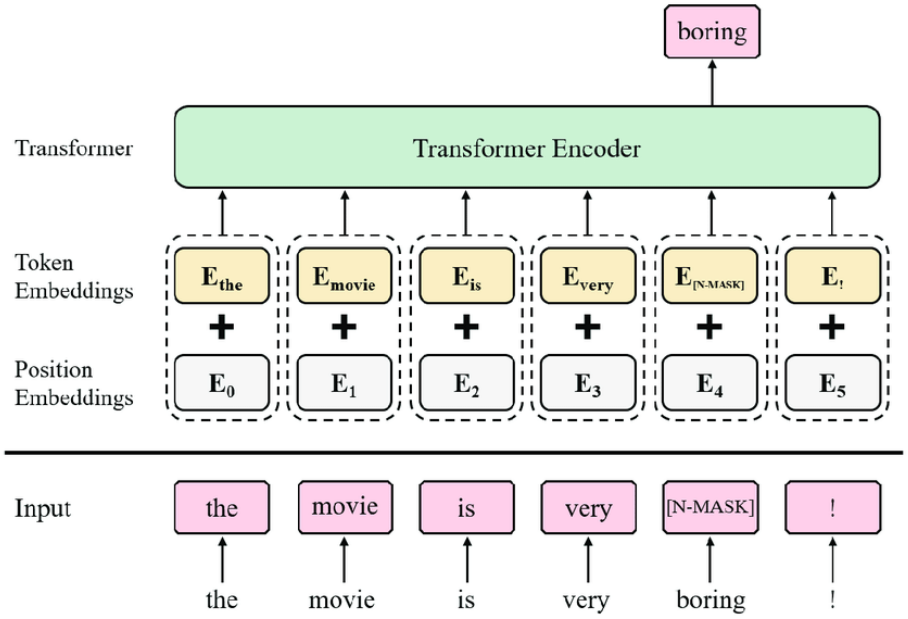
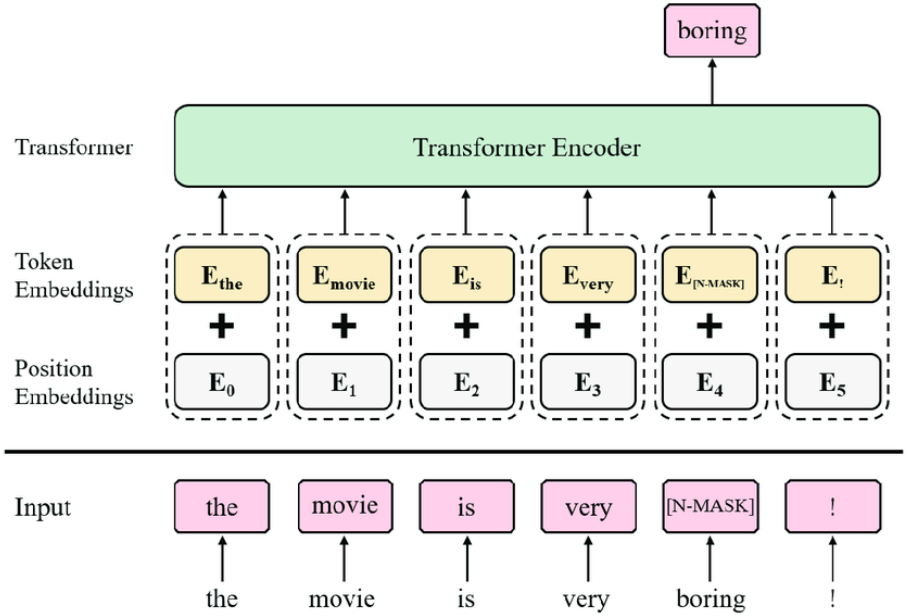
(
. . .

BERT - Pretrained Transformer Encoder

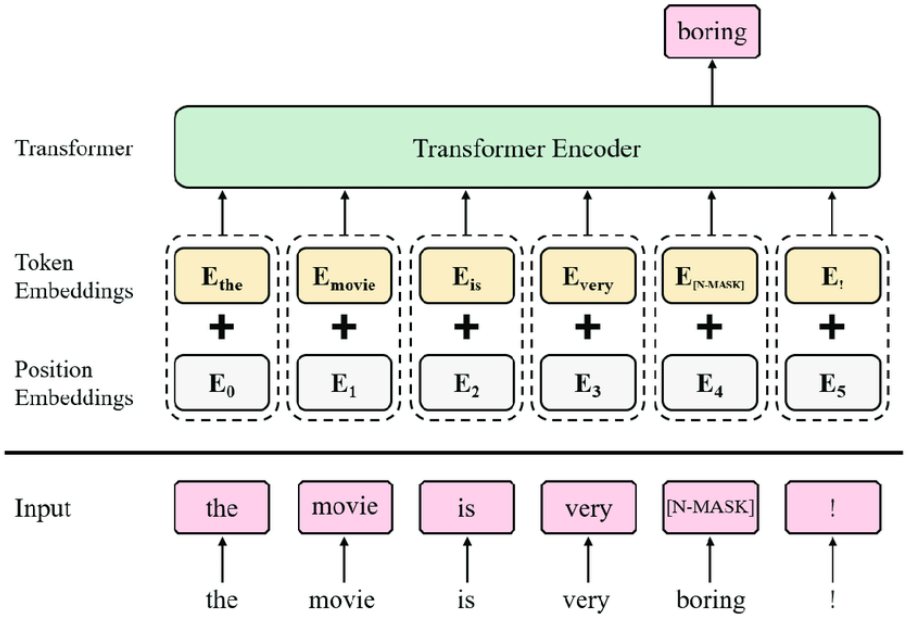


BERT - Pretrained Transformer Encoder



Pre-training:
Task agnostic Masked Language Model.

BERT - Pretrained Transformer Encoder



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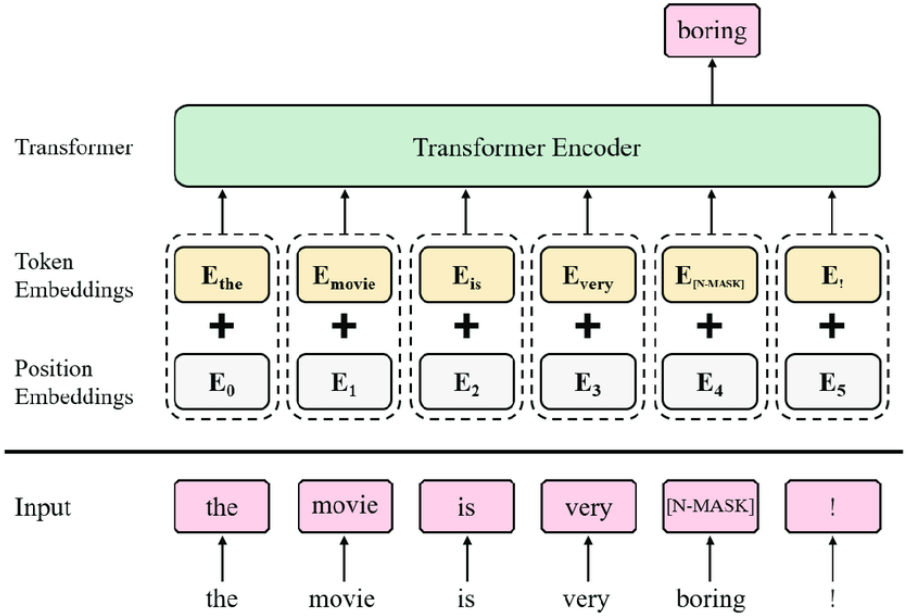
BERT - Pretrained Transformer Encoder



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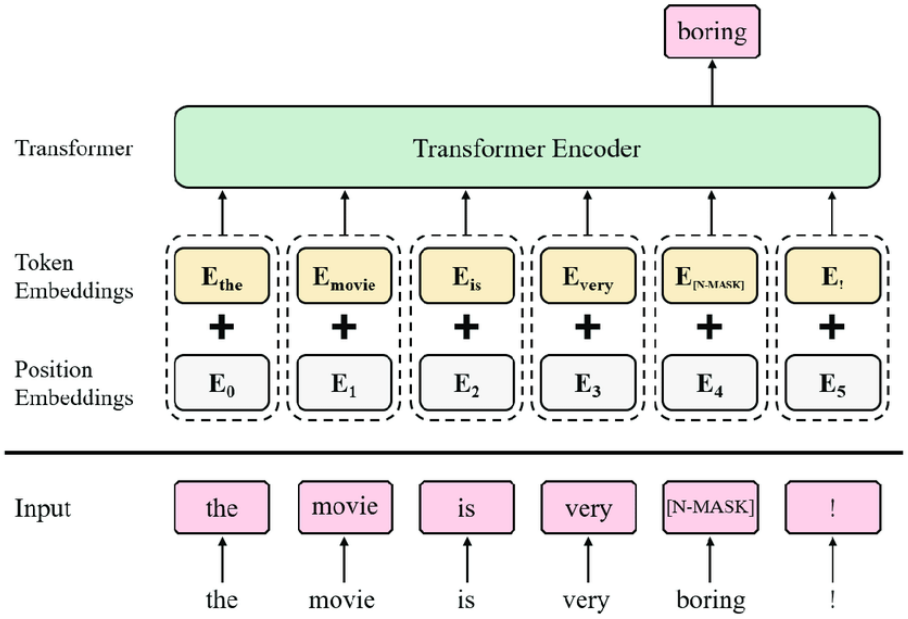

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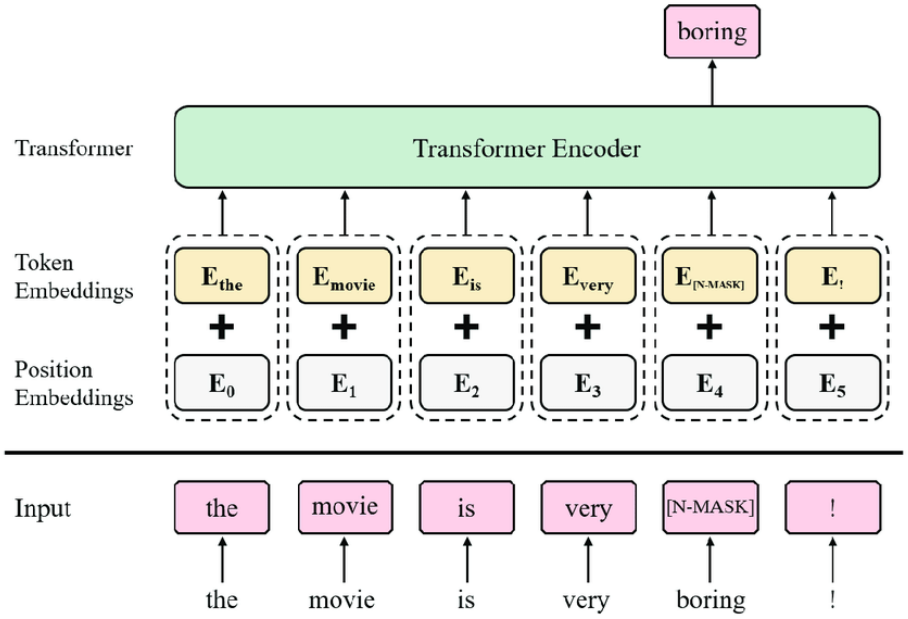
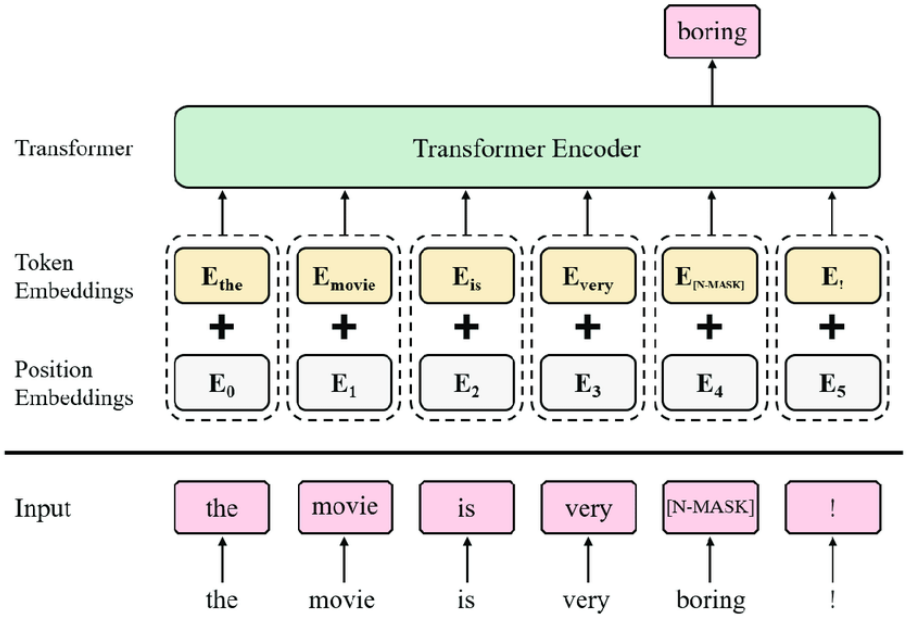
BERT - Pretrained Transformer Encoder



Pre-training:
Task agnostic Masked Language Model.

SE usage: Better **Suitable** for **Understanding Code**.

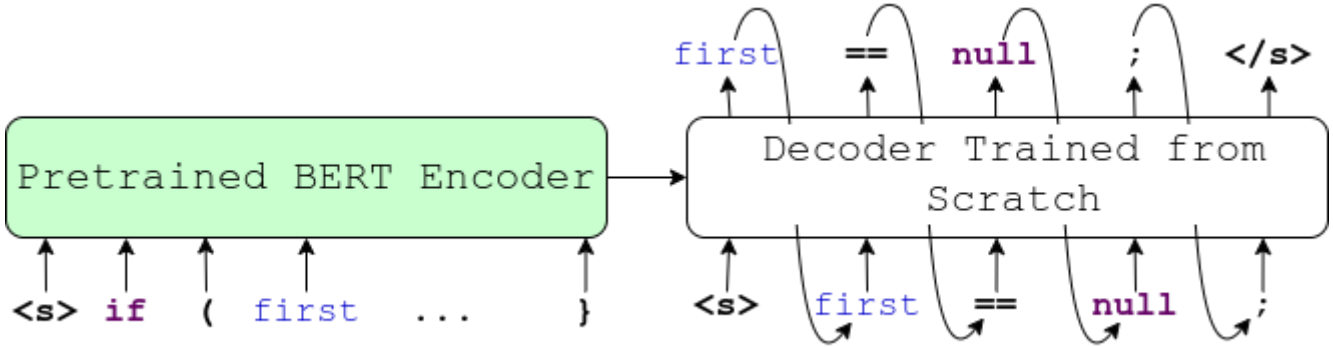
BERT - Pretrained Transformer Encoder



Pre-training:
Task agnostic Masked Language Model.

1. CuBERT - Kanade *et. al.* 2020.
2. CodeBERT - Feng *et. al.* 2020.
3. GraphCodeBERT - Guo *et. al.* 2021

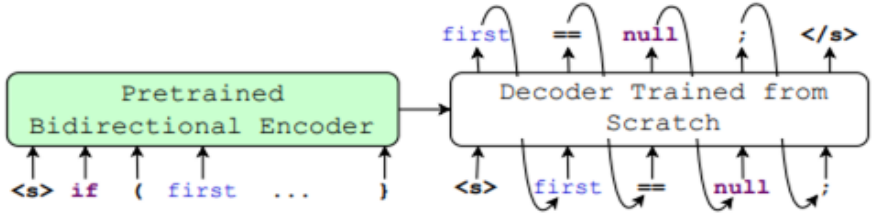
SE usage: Better **Suitable** for **Understanding Code**.



Knowledge about **generation** is **not** embedded in Decoder.

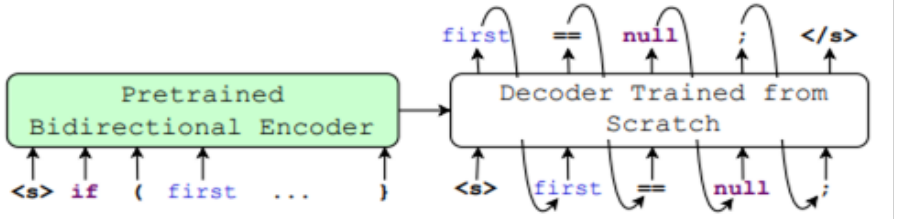
CodeBERT vs. CodeGPT vs. PLBART

CodeBERT vs. CodeGPT vs. PLBART

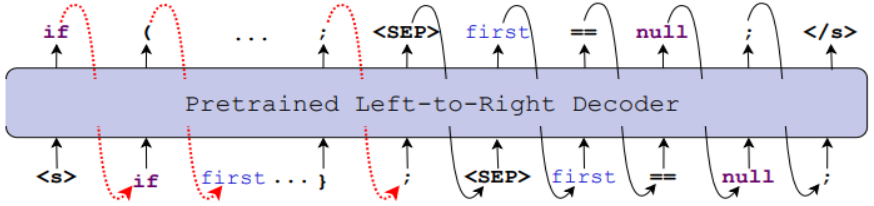


BERT

CodeBERT vs. CodeGPT vs. PLBART

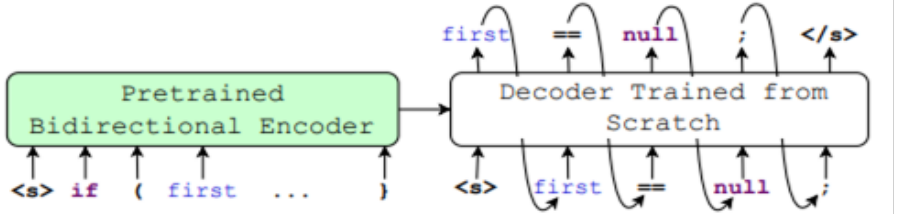


BERT

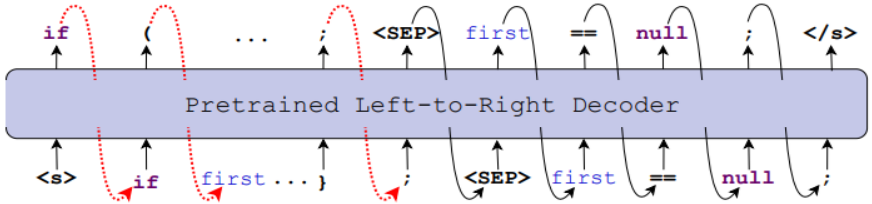


GPT

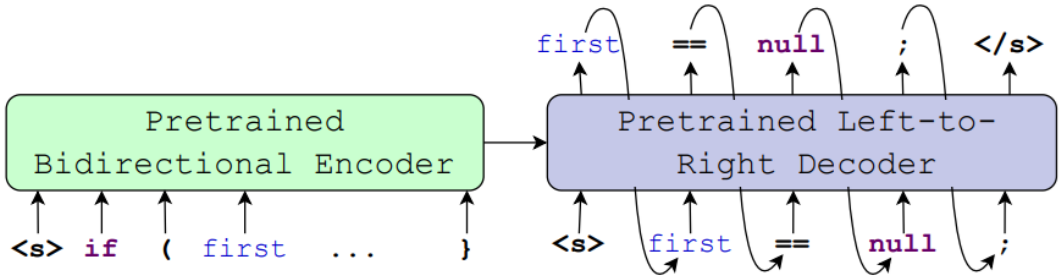
CodeBERT vs. CodeGPT vs. PLBART



BERT



GPT



PLBART